# Weeds

VOLUME 8
JANUARY 1960
NUMBER 1

*Journal of the Weed Society of America*

# *Weeds*

*Issued Quarterly by the Weed Society of America*

C. J. WILLARD, *Editor*, Department of Agronomy, H. & F. Bldg., 1827 Neil Ave., The Ohio State University, Columbus 10, Ohio.

W. C. JACOB, *Business Manager*, Department of Agronomy, University of Illinois, Urbana, Illinois.

EDITORIAL COMMITTEE

O. C. LEE, Department of Botany and Plant Pathology, Purdue University, Lafayette, Indiana.

R. A. PETERS, Department of Plant Science, University of Connecticut, Storrs, Connecticut.

W. C. ROBOCKER, Crops Research Division, ARS, USDA, State College of Washington, Pullman, Washington.

E. G. RODGERS, Department of Agronomy, University of Florida, Gainesville, Florida.

WEEDS is a quarterly journal published by the Weed Society of America. Editorial office is located at Department of Agronomy, H. and F. Bldg., The Ohio State University, 1827 Neil Ave., Columbus 10, Ohio. Printing is by the W. F. Humphrey Press Inc., Geneva, New York. Subscription price is $6.00 yearly for four issues; single copies $1.50. Address all communications regarding subscriptions, advertising, and reprints to W. C. Jacob, Department of Agronomy, University of Illinois, Urbana, Illinois. Inquiries concerning information on manuscripts and other material for publication should be addressed to the Editorial Office. All checks, money orders, and other remitttances should be made payable to the Weed Society of America.

Entered as second-class matter at the post office at Urbana, Illinois with additional entry at Geneva, New York.

# Table of Contents


| | Page |
|---|---|
| Effect of 2,4-D on Germination of Pigweed Seed. M. Rojas-Garciduenas and Thor Kommedahl | 1 |
| Factors Affecting the Response of *Zea mays* and *Sorgum halepense* to Sodium 2,2–Dichloropropionate. H. H. Funderburk, Jr., and D. E. Davis | 6 |
| Experiments with Herbicides in Soils. A. S. Crafts and Harold Drever | 12 |
| Evidence for Hydrolysis of Esters of 2,4–D during Absorption by Plants. A. S. Crafts | 19 |
| Reduction of Annual Bluegrass, *Poa annua*, in Bentgrass Turf by the Use of Chemicals. R. E. Engel and R. J. Aldrich | 26 |
| Effects of Amitrol on the Respiratory Activities of *Zea mays*. C. G. McWhorter and W. K. Porter | 29 |
| An Explanation for the Selective Control of Barnyardgrass in Rice with CIPC. John B. Baker | 39 |
| Molecular Structure and Herbicide Adsorption. A. C. Leopold, P. van Schaik and Mary Neal | 48 |
| Achene Development of Canada Thistle and Perennial Sowthistle. Lyle A. Derscheid and Robert E. Schultz | 55 |
| Chloro-substituted Benzoic Acids for Control of Field Bindweed. W. M. Phillips | 63 |
| Response of Pensacola Bahiagrass to Herbicides. C. C. Black and E. G. Rodgers | 71 |
| Dalapon and Substituted Urea Herbicides for Control of Seed-bearing *Spartina* (Cord Grass) in Inter-tidal Zones of Estaurine Marsh. D. S. Ranwell and B. M. Downing | 78 |
| Periderm Formation in Hypocotyl of *Gossypium hirsutum* and its Effect upon Penetration of an Herbicidal Oil. R. D. Palmer and W. B. Ennis, Jr | 89 |
| Control of Bedstraw (*Galium mollugo*) with Alpha-Phenoxypropionic Acid Derivatives. Jal S. Parakh and Marvin M. Schreiber | 94 |
| Chemistry of Some Amino Acid Derivatives of Phenoxyalkylbutyric Acids. Charles F. Krewson, Edward J. Saggese and Thomas F. Drake | 107 |
| Leafy Spurge Control with Cultivation, Cropping and Chemicals. Lyle A. Derscheid, Keith E. Wallace and Russel L. Nash | 115 |
| Chemical Control of *Typha angustifolia* L. var. *brownii*. E. Levi | 128 |
| News and Notes | 138 |
| Sustaining Members | 139 |
| Bibliography of Weed Investigations, April to June 1959 | 141 |


# Advertisers Index


| | |
|---|---|
| Chipman Chemical Co. | ii |
| Spraying Systems Co. | iii |
| duPont de Nemours & Co. | iv |
| U. S. Borax & Chemical Corp. | v |
| Stauffer Chemical Co. | vi |

**ATLACIDE:** Safer chlorate weed killer...widely used for non-selective eradication of bindweed, Canada thistle, quack grass, Johnson grass and other tough perennials. Kills roots...discourages regrowth. Applied dry or dissolved in water.

**ATLACIDE–2,4-D:** Offers dual killing action of sodium chlorate and 2,4–D.

**CHLOREA:** A combination of sodium chlorate, borate and monuron in powder form. Kills weeds and grasses. Combines the proven effectiveness of chlorate on deep-rooted weeds with the soil-surface action of monuron on shallow-rooted grasses and annual seedling growth. Lasting residual effect inhibits new growth. Does not create a fire hazard when used as directed. Applied dry or as a water-mixed spray.

**CHLOREA GRANULAR** Similar to Chlorea, but a "pelletized" material. No mixing...easy to apply by hand or with mechanical spreader.

**CHLORAX "40":** A composition of sodium chlorate and borate...for weed and grass control. Has lasting residual effect. Does not create a fire hazard. Applied dry or as a spray.

**ATLAS "A":** A 40% sodium arsenite solution (4 lbs. arsenic trioxide per gal.). Destroys vegetation and algae in ponds and lakes. Controls certain turf weeds. Used as general weed killer and to kill trees and stumps. Also used to kill potato vines prior to harvesting.

**SODIUM ARSENITE:** A powder containing 75% arsenic trioxide. Used for the same purposes as Atlas "A". Applied dry or as a spray.

**CHIP-CAL:** New low-lime calcium arsenate formulation in *granular* and spray *powder* forms. Used as crabgrass preventatives for established turf. Applied any time before crabgrass seed starts to germinate.

**2,4-D & 2,4,5-T:** 2,4–D Amine and 2,4–D Ester liquids; 2,4–D Ester dusts; Low Volatile 2,4,5–T and Brush Killer.

**METHOXONE:** Contains MCP sodium salt. Used for control in small grains, flax, rice and grass. Controls same weeds as 2,4-D; considered safer for selective spraying.

**BUTOXONE:** A liquid containing 4–(2,4–DB). For selective control of many broadleaf weeds in established alfalfa and certain other legumes.

*Write for Weed Control Booklets*

**CHIPMAN CHEMICAL COMPANY, INC.**

**Chicago, Ill. Bound Brook, N. J. Portland, Ore.**
**Palo Alto, Calif. . Pasadena, Tex. . Bessemer, Ala.**

***Manufacturers of Weed Killers Since 1912***

SPRAYING SYSTEMS
TeeJet
SPRAY NOZZLES

the precision nozzle for effective spraying

Supplied in a full range of interchangeable orifice tip and strainer sizes to meet every capacity requirement. TeeJet Spray Nozzles for Weed Control by spraying make it possible to take maximum advantage of the chemical and sprayer unit. TeeJet nozzles are precision built and provide a flat spray with uniform distribution. Atomization is properly controlled to give coverage with an absolute minimum of driftage. Patented tip design, with set-back orifice opening protects precision orifice from accidental damage. TeeJet spray nozzles are built for use on spray booms and portable sprayers.

TEEJET SPRAY NOZZLE male pipe connection

TEEJET SPRAY NOZZLE female pipe connection

INTERCHANGEABLE ORIFICE TIPS flat and cone spray types

**OFF-CENTER SPRAY NOZZLES**

Spraying Systems Spray Nozzles with TeeJet tips are supplied in a variety of special body types to meet any unusual spraying requirement. For example, one type of off-center spray nozzle with swivel body provides a flat spray up to 35 feet wide for spraying areas with a single nozzle, that are not accessible with a boom.

**SUPPLEMENTARY EQUIPMENT**

Complete accessories relating to nozzle use are supplied. These include strainers, special nozzle fittings, and hand valve equipment.

TeeJet Spray Nozzles are supplied for Weed Control... as well as all other types of agricultural spraying. For complete information and reference data write for Catalog 50.

SPRAYING SYSTEMS CO.

*Engineers and Manufacturers*

3296 RANDOLPH STREET BELLWOOD, ILLINOIS

## For Agriculture and Industry . . .

# Du Pont
# WEED KILLERS

***offer new economies***
***and efficiency in killing***
***weeds, grass and brush***

**KARMEX®** diuron for weed control in many crops; irrigation and drainage ditches; and industrial areas.

**KARMEX® DL** for pre-emergence weed control in cotton.

**TELVAR®** monuron for weed control in many crops; irrigation and drainage ditches; and industrial areas.

**KLOBEN®** neburon for weed and grass control in nursery plantings and tomatoes.

**DYBAR®** fenuron—a pelleted product for dry application to the soil for control of brush in fence rows, drainage ditches, utility and railroad right-of-ways, and other non-cultivated areas.

**TRYSBEN® 200**, a new weed killer based on trichlorobenzoic acid, for control of bindweed and other noxious weeds; mixed broadleaf weeds; and certain woody vines and brush.

**AMMATE® X** for long-term, low-cost brush control.

DU PONT
REG. U. S. PAT. OFF.

Better Things for Better Living . . . *through Chemistry*

Four easy ways to Destroy Weeds

**1. UREABOR®**

A nonselective, granular complex of sodium borate and substituted urea. Low application rates are a feature. Apply with the special new PCB Spreader for best results.

**2. BENZABOR®**

A blend of trichlorobenzoic acid and sodium borates. Kills deep-rooted, noxious weeds. Low application rates give maximum control with the utmost economy; use the convenient PCB Spreader.

**3. POLYBOR-CHLORATE®**

Highly soluble; for spray or dry application. It gives a quick knock-down; destroys top growth and roots. A general nonselective herbicide.

**4. Concentrated BORASCU®**

A nonselective, granular material. Apply by hand or with a mechanical spreader. Long residual action.

*When you want Nonselective Herbicides*

*for Dependable Action*

UNITED STATES BORAX

& CHEMICAL CORPORATION

630 Shatto Place, Los Angeles 5, California

# = NEWS ABOUT VAPAM® =

### New Application Technique Suggested for Some Crops

VAPAM dosage may be reduced in many cases up to 50% with equal or better results if the treated area is covered with a plastic, paper or fabric tarp. The cover should be loosely spread over the treated area immediately after application, and left on for 24 to 48 hours for best results. The amount of water used to drench VAPAM into the soil may be reduced. When a tarp is used, it may be possible to prepare the seedbed just before applying VAPAM if soil moisture is adequate. Do not apply VAPAM to dry soils.

### Careful Soil Preparation a Must

Wide-scale use of VAPAM continues to demonstrate the importance of careful soil preparation. Careful cultivation of the area to be treated should be done a *week* before application when no cover is used. All clods should be broken up, and soil should be loosened deeply. The soil should then be kept moist until time of treatment. If the soil becomes crusted, it should be cultivated lightly just before application of VAPAM. Experience has shown that proper soil preparation is the most important step in applying VAPAM. Soil temperature must be between 60°-90°F. at a 3-inch depth.

### Dosage Recommendations Now More Detailed

Dosage recommendations have been made more explicit on the label. Potting and top-dressing soil treatments have been added.

### Copy of New Label Available

Write to Stauffer for a copy of the new label, or for further information on VAPAM. Address your inquiry to Stauffer Chemical Company, Agricultural Chemicals Division, 380 Madison Avenue, New York 17, N. Y., or 636 California Street, San Francisco 8, Calif.

Stauffer CHEMICALS SINCE 1885

® VAPAM is Stauffer Chemical Company's trade-mark (registered in principal countries) for *sodium methyl dithiocarbamate*, a soil fumigant.

Weeds

JOURNAL OF THE WEED SOCIETY OF AMERICA

VOLUME 8 JANUARY 1960 NUMBER 1

# The Effect of 2,4–D on Germination of Pigweed Seed[1]

M. ROJAS-GARCIDUENAS and THOR KOMMEDAHL[2]

## INTRODUCTION

THE use of 2,4–dichlorophenoxyacetic acid (2,4–D) to control annual weeds such as pigweed *(Amaranthus retroflexus* L.) is common. Abundant evidence has been published to show that 2,4–D affects germination and subsequent seedling development. Allard et al. (1) found that 2,4–D delayed germination and caused abnormalities in seedlings of 22 broadleaf and cereal species. Elongation of radicles was inhibited in mustard seedlings (7) and in both nondormant and embryo-dormant seeds (4) as well as in seeds with impermeable seed coats (4). Germination can not only be delayed but can be inhibited (4, 5, 6), although at low concentrations of 2,4–D germination may be accelerated (6). Leachates produced by rainfall coming in contact with 2,4–D in soil were deleterious to seeds of flax and corn (2). To explore further the effects of 2,4–D on seeds, germination tests were made with scarified and nonscarified seeds of pigweed and on the effect on yield and germination of seeds harvested from pigweed plants that were sprayed with sublethal doses of 2,4–D in field plots.

## MATERIALS AND METHODS

Because of low germination, pigweed seeds were first scarified in concentrated $H_2SO_4$ prior to broadcasting them in field plots, 7 x 7 ft. Forty-five days after sowing, the terminal flowers began to bloom, and at this time plants in each of 3 field plots were sprayed with an alkanolamine salt of 2,4–D at the rate of 1 lb/A.

Seeds were harvested from 5 plants from each of 3 treated plots plus the controls and stored dry for 10 days and weighed. Tests for germination were made at 15 days and again at 5 months after harvest, and were made in quadruplicate (100 seeds per replicate) on moist filter paper in Petri plates at about 25° C under alternate light and darkness. Continuous light was not used as preliminary

[1]Paper No. 3871, Scientific Journal Series, Minnesota Agricultural Experiment Station, St. Paul, Minnesota.

[2]Former Graduate Student, and Associate Professor, respectively, Department of Plant Pathology and Botany, University of Minnesota, Institute of Agriculture, St. Paul, Minnesota.

tests showed a statistically significant reduction in percentage germination under continuous illumination compared to either continuous darkness or alternate light and darkness (8). Seed used to test the effect of 2,4–D on germination was from about 3 months old (Tables 1 and 2) to 8 months old (Table 3), and data were obtained on 100 or 200 seeds per treatment.

*Table 1.* Germination of pigweed seeds scarified with $H_2SO_4$ and immersed in an alkanolamine salt of 2,4–D at different concentrations for different periods of time compared with a nonscarified control.

| Hours of immersion | | Per cent germination after immersion in 2,4-D at indicated ppm | | | | |
|---|---|---|---|---|---|---|
| 2,4-D | Water | 0 | 5 | 25 | 50 | 500 |
| 0 | 30 | 41 | — | — | — | — |
| 1 | 29 | — | 48 | 46 | 50 | 46 |
| 5 | 25 | — | 3 | 3 | 1 | 1 |
| 20 | 10 | — | 4 | 1 | 2 | 1 |
| 30 | 0 | — | 3 | 3 | 0 | 0 |

*Table 2.* Germination of nonscarified pigweed seeds immersed in an alkanolamine salt of 2,4–D at different concentrations for different periods of time.

| Hours of immersion | | Per cent germination after immersion in 2,4-D at indicated ppm | | | | |
|---|---|---|---|---|---|---|
| 2,4-D | Water | 0 | 5 | 25 | 50 | 500 |
| 0 | 30 | 42 | — | — | — | — |
| 1 | 29 | — | 45 | 68 | 68 | 48 |
| 5 | 25 | — | 60 | 60 | 70 | 46 |
| 20 | 10 | — | 68 | 58 | 47 | 33 |
| 30 | 0 | — | 65 | 55 | 36 | 29 |

## RESULTS AND DISCUSSION

### *Effect of 2,4–D on yield and germination of seed from sprayed plants.*

Symptoms of epinasty from 2,4–D application were apparent 1 to 3 days after treatment. Also sprayed plants grew faster than the controls. At 5 to 15 days, leaves and stems became chlorotic and necrotic and purple pigmentation was visible on stems. The terminal flowers wilted and axillary flowers developed slowly. At 10 to 15 days after spraying necrosis was extensive on stems, cracks developed on apical parts of stems, and except for branches at the base of the stem, plants appeared to be dead. Finally, after 4 to 5 weeks the basal branches produced new branches and leaves, then developed axillary and terminal flowers which set seed. Regrowth occurred only at basal portions of stems.

Seed was harvested from sprayed and unsprayed plants, and the weight per 1000 seeds was 0.31 gm for sprayed and 0.32 gm for unsprayed plants. However the average yield per plant for 5 plants in each of 3 sprayed plots was 11 gm (34,000 seeds/plant) compared to 24 gm (75,000 seeds/plant) for the unsprayed plants. These figures

for unsprayed plants are based on high plant densities and are lower than those reported by Stevens (9); however, his figures are based on well developed plants growing at low plant densities.

Tests for germination in Petri plates were made from seed of both sprayed and unsprayed plants. Tested 15 days after harvest, seed from unsprayed plants germinated 2 per cent and seed from sprayed plants germinated 11 per cent; the LSD value at 1 per cent was 4. Tested 5 months after harvest, seed from unsprayed plants germinated 10 per cent and seed from sprayed plants germinated 50 per cent; the LSD value at 1 per cent was 23. There is apparent also a 5-fold increase in germination from the first to the second time that germination tests were made. Barton (3) has shown that the percentage germination of pigweed seed increases with age.

*Effect on germination of seeds treated with 2,4–D.*

It is known that hard seed coats protect the seed from the effects of 2,4–D in some species (4). To determine whether this was true with pigweed, seeds were scarified with sulfuric acid prior to treatment with 2,4–D. Sulfuric acid alone increased significantly the germination of pigweed seeds even when the seeds were stored dry for 1 day after acid treatment, but when the seeds were stored dry from 3 to 10 days after treatment with the acid the percentage germination was not significantly different from that of nontreated seeds. Forty-five per cent of the seed treated with sulfuric acid germinated within 24 hours and 18 per cent of nontreated seed germinated.

To study the action of 2,4–D on the percentage germination of scarified seeds, seeds were treated with sulfuric acid and then immersed in different concentrations of 2,4–D for different times. After immersion they were rinsed in tap water for 15 minutes and allowed to germinate. One hundred seeds not treated with acid nor with 2,4–D were used as controls. All seeds were immersed for 30 hours in liquid, either 2,4–D or water, before being placed in Petri plates. The results are shown in Table 1. The 2,4–D inhibited germination except when the seeds were immersed for only 1 hour in the herbicide prior to germination in Petri plates. However there were no differences between concentrations of 2,4–D in their effects on percentage germination.

Both concentration and exposure time affected the reaction of nonscarified seed (Table 2). The percentage germination of such seed was increased by soaking 5 to 30 hours in 5 ppm solution of 2,4–D. One to 5 hours in concentrations of 25 to 50 ppm also increased percentage germination, but exposures of 20 to 30 hours at 500 ppm resulted in less germination than the control.

This effect was found also in an experiment with two concentrations, 5 and 500 ppm, at 1 to 30 hours of immersion, using nonscarified seed (Table 3). There were two controls, one in water and one on moist filter paper. Of the seeds germinated in water about one fourth sank and the remainder floated. However, no difference in the germination of sunken and floating seeds was

*Table 3.* Germination of pigweed seeds in water after treatment with two concentrations of the alkanolamine salt of 2,4–D for different periods of time.

| Ppm of 2,4-D | Hours of immersion | | Germination per cent[a] |
|---|---|---|---|
| | 2,4-D | Water | |
| 0[b] | 0 | 30 | 66.5 |
| 0[c] | 0 | 30 | 64.5 |
| 5 | 1 | 29 | 61.0 |
| 5 | 5 | 25 | 71.5 |
| 5 | 20 | 10 | 82.0 |
| 5 | 30 | 0 | 80.0 |
| 500 | 1 | 29 | 66.5 |
| 500 | 5 | 25 | 66.5 |
| 500 | 20 | 10 | 55.5 |
| 500 | 30 | 0 | 52.5 |
| LSD at 5 per cent level | | | 6.8 |
| LSD at 1 per cent level | | | 9.7 |

[a]Based on 200 seeds per treatment.
[b]Control: germination in water.
[c]Control: germination on filter paper.

observed. There were no significant differences between the controls and the 1-hour treatment with 2,4–D, regardless of concentration. Also, there was no significant difference between the seeds germinated in water and those germinated on filter paper. The treatments with 5 ppm for 20 to 30 hours increased significantly the percentage germination; however, treatments with 500 ppm for 20 to 30 hours decreased it significantly.

## SUMMARY

Fifteen days after harvest of seed from pigweed plants sprayed in the field with an alkanolamine salt of 2,4–D (1 lb/A), seed germinated 11 per cent while seed harvested from unsprayed plants germinated 2 per cent. Five months after harvest, 50 per cent of the seed from sprayed plants germinated while 10 per cent of the seed from unsprayed plants germinated. Unsprayed plants yielded 24 gm of seed per plant while sprayed plants yielded 11 gm of seed per plant.

The germination of scarified seeds immersed in 5, 25, 50, and 500 ppm solutions of 2,4–D for 1 hour was about the same as the controls. However, germination of seed immersed in the same concentrations of 2,4–D for 5, 20, or 30 hours was almost completely inhibited.

Nonscarified seeds immersed in 2,4–D germinated better than seeds immersed in water (control) at the following concentrations of 2,4–D: 25 and 50 ppm for 1 hour; 5, 25, 50 ppm for 5 hours; and 5 and 25 ppm for 20 or 30 hours. On the other hand, germination was inhibited at 500 ppm for either 20 or 30 hours.

## LITERATURE CITED

1. ALLARD, R. W., DEROSE, H. R., and SWANSON, C. P. Some effects of plant growth-regulators on seed germination and seedling development. Bot. Gaz. 107:575–583. 1946.

2. ARAKERI, H. R., and DUNHAM, R. S. Environmental factors relating to the preemergence treatment of corn with 2,4–D and soybeans with TCA. Minnesota Agr. Exp. Sta. Tech. Bul. 190. 1950.
3. BARTON, L. V. Respiration and germination studies of seeds in moist storage. Ann. New York Acad. Sci. 46:185–208. 1945.
4. EVERSON, L. E., and DUNHAM, R. S. The effect of 2,4–dichlorophenoxyacetic acid on certain weed and crop seeds. Minnesota Agr. Exp. Sta. Tech. Bul. 197. 1951.
5. HAMNER, C. L., MOULTON, J. E., and TUKEY, H. B. Effect of treating soil and seeds with 2,4–D on germination and development of seedlings. Bot. Gaz. 107:352–361. 1946.
6. HSUEH, Y. L., and LOU, C. H. Effects of 2,4–D on seed germination and respiration. Science 105:283–285. 1947.
7. MITCHELL, J. W., and BROWN, J. W. Relative sensitivity of dormant and germinating seeds to 2,4–D. Science 106:266–267. 1947.
8. ROJAS-GARCIDUENAS, M., and KOMMEDAHL, T. Effect of light and 2,4–D on germination of pigweed seeds. Res. Rpt. NCWCC 12:77. 1955.
9. STEVENS, O. A. Weights of seeds and numbers per plant. Weeds 5:46–55. 1957.

# Factors Affecting the Response of *Zea mays* and *Sorgum halepense* to Sodium 2,2–Dichloropropionate[1]

H. H. Funderburk, Jr., and D. E. Davis[2]

Sodium 2,2–dichloropropionate (dalapon) has been one of the more successful herbicides in controlling grass type weeds that have an abundance of underground rhizomes such as Johnsongrass *(Sorgum halepense)* and quackgrass *(Agropyron repens)*.

Anderson and Hauser (1, 6) found with Johnsongrass that best control was obtained when dalapon was applied as a foliar spray to vigorously growing young plants. Ries and Vengris (10, 12) reached a similar conclusion when they used dalapon for the control of quackgrass.

Hauser and Thompson (5) found that the translocation of dalapon was not critically affected by low soil moisture, reduced sunlight, or the use of additional wetting agents in the spray solution. Standifer and Ennis (11), however, found that the rate of absorption of dalapon was more efficient or rapid under conditions of high humidity.

The purpose of this study was to add some information to the existing knowledge as to the effects of age, spray date, and rate on toxicity of dalapon to Johnsongrass. Corn was added as the second test plant due to its ease of culturing, susceptibility to dalapon, and because it was possible to select varieties of genetic homogeneity. Other experiments were added to determine if dalapon was carried over in the grain of corn to succeeding generations, to compare root versus shoot absorption of dalapon, and to determine if there were any differences in responses of various corn hybrids to dalapon.

## Materials and Methods

*Effects of age, spray date, and rate on toxicity of dalapon to corn.* This test was conducted on a Norfolk sandy loam soil. It was replicated four times and each plot was a row 50 ft. long. Corn of five planting dates, April 9, 16, 23, 30, and May 6, was sprayed on three dates, May 9, 16, and 23, thus providing corn of the same three ages (2, 3, and 4 weeks) at each spraying date. The rates of dalapon on an active ingredient basis were 0, 2, and 8 lb/A. Dixie 18 corn was planted in normally prepared and fertilized soil and thinned to 15 to 20 in apart. The various spray treatments were applied 10 in above the tops of the plants at 30 psi and 54 gal/A.

Growth in height and green weights were used to evaluate plant response to dalapon in the various treatments. Ten randomly selected plants from each row were measured 3, 4, 5, and 6 weeks after chemical treatment and green weights were obtained when

[1]This paper is primarily from a M.S. thesis presented by the senior author to the School of Graduate Studies, Alabama Polytechnic Institute, Auburn, Alabama.

[2]Assistant in Botany and Botanist, Agricultural Experiment Station of the Alabama Polytechnic Institute, Auburn, Alabama.

plants were 9 to 13 weeks old. Additional data were obtained from each treatment on the number and length of internodes and the number of whorls of brace roots. A record of rainfall and maximum-minimum temperatures was kept during the experiment. Two analyses were made, one based on planting dates and one based on ages.

*Carryover of dalapon to succeeding generations.* Seeds were harvested from all plots that received the 0 and 2 lb/A rates of dalapon in the preceeding test. The seeds were collected by taking one ear from each of ten randomly selected stalks in each row. Several grains from the center of each ear were shelled off, and these ten samples were composited as representative of the row. Each plot for this test consisted of a 25 ft row into which 50 seeds were hand dropped.

*Root versus shoot absorption of dalapon.* This phase of the investigation involved three treatments which were applied in quadruplicate to Dixie 18 corn plants that were grown in Hoagland and Arnon's Solution 2 (7). The treatments were a check, roots dipped for 5 seconds in a 5,000 ppm solution of dalapon, and shoots dipped in a similar manner. After each plant was dipped, it was allowed to drain for 10 seconds and then was placed between moist paper towels for 1 hour and 15 minutes. At the end of this absorption period, the treated portions of the plants were rinsed in five successive containers of water and the plants were returned to the nutrient solution. Bioassays included height measurements and dry weights. This test was repeated three times.

*Response of different hybrids.* This experiment was conducted to determine if there were any variations in the responses of different corn hybrids to dalapon. It involved 3 replications, 11 hybrids and 2 rates, as indicated in Table 4[3]. Height measurements were made on 10 randomly selected plants from each row 2, 3, and 4 weeks after chemical treatment.

*Effects of age, spray date, and rate on toxicity of dalapon to Johnsongrass.* Johnsongrass that had been growing in 8-in pots in the greenhouse for several months was used for this test. The Johnsongrass had well developed root systems and rhizomes. Three weeks prior to the first spraying the shoots of all Johnsongrass plants were cut off and allowed to resprout. The test was replicated 4 times and consisted of three rates of dalapon, 0, 5, and 20 lb/A, and 4 ages when sprayed, 3, 6, 9, and 12 weeks. Two weeks after each spraying the shoots in each pot were cut off and the oven-dry weight recorded. The grass was then allowed to resprout and grow for three weeks, at which time the shoots were again cut off and oven-dry weight recorded.

## RESULTS AND DISCUSSION

*Effects of age, spray date, and rate on toxicity of dalapon to corn.* The effects of the various spray rates on the height of corn sprayed

[3]The seeds for this experiment were obtained from the Agronomy and Soils Department, A. P. I.

at various ages are shown in Table 1. As expected, the rate of dalapon application influenced strongly the growth in height of corn. The 8 lb treatment stopped the growth in height of corn at all ages and at all spraying dates. The 2 lb rate of dalapon also had a strong influence on the height of corn, though not enough to completely prevent growth (Table 1). There was no evidence that age of corn

*Table 1.* Height of corn at varying times after spraying at varying ages with varying rates of dalapon.[a]

| Weeks after spraying | Height in cm of corn sprayed at the age of | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 weeks | | | 3 weeks | | | 4 weeks | | |
| | Ck | 2 lb | 8 lb | Ck | 2 lb | 8 lb | Ck | 2 lb | 8 lb |
| 3 | 99 | 66 | 26 | 118 | 87 | 44 | 142 | 85 | 60 |
| 4 | 134 | 91 | 27 | 159 | 114 | 44 | 182 | 99 | 59 |
| 5 | 177 | 116 | 27 | 202 | 142 | 44 | 215 | 123 | 56 |
| 6 | 215 | 136 | 28 | 236 | 153 | 43 | 249 | 124 | 54 |

[a]All ages of corn and all waiting periods are represented equally in every average though corn sprayed at 2 weeks represents 3 plantings made April 23, 30 and May 7, while corn sprayed at 3 weeks represents 3 plantings made April 16, 23, and 30, and corn sprayed at 4 weeks represents 3 plantings made April 9, 16, and 23.

affected the response to rates of dalapon; that is, the small differences in the responses of the various ages of corn to the herbicide shown in Table 1 could well be chance events. Spray dates were found to influence the toxicity of the chemical, with the 2 lb rate being nearly as toxic as the 8 lb rate at the first spraying, but not at later sprayings (Table 2). The foregoing statements are based on statis-

*Table 2.* The effect of spray dates with varying rates of dalapon on the height of corn.[a]

| Spray date | Height of corn in cm | | |
|---|---|---|---|
| | Rates | | |
| | Ck | 2 lb | 8 lb |
| May 9 | 157 | 47 | 33 |
| May 16 | 175 | 142 | 48 |
| May 23 | 200 | 145 | 47 |

[a]All ages of corn and all waiting periods after spraying are represented equally in every average. However, corn at the second and third spray dates was necessarily from plantings made one and two weeks later than those used at the first spray date.

tical tests using the conventional 5 percent probability level to judge significance. There did not seem to be any obvious correlation between the relative toxicities on the various dates of application and observed weather phenomena immediately prior to, during, or following chemical treatment. The green weight data confirmed the findings in the height study.

A detailed study of randomly selected plants indicated that dalapon decreased the stem length by decreasing the length of the internodes without affecting the number of internodes. Shortening of

the internodes was most pronounced in the upper one-third of the internodes, but was found also in the middle one-third at the 8 lb rate and occasionally at the 2 lb rate. There was no evidence of death in the cells of the intercalary meristems, but the dalapon interfered with elongation. The 8 lb rate seriously interfered with tassel development and there was an indication that it stimulated development of additional whorls of brace roots. Some of the major morphological abnormalities of corn caused by dalapon were similar to the expressions of the brachytic gene and the rolled gene (2, 8).

*Carryover of dalapon to succeeding generations.* Dalapon could possibly affect succeeding generations of corn in two ways. First, it could be carried over in the grain as dalapon. Ennis (4) has demonstrated such a carry over of 3–amino–1,2,4–triazole in corn. Engle and McIllrath (3) and Miller et al. (9) have demonstrated also a carryover of 2,4–D in cotton. Second, dalapon could affect development of the grain while it is still attached to the parent plant and thus influence the percentage of germination or the vigor of the seedling. The plants treated with dalapon from which seeds were harvested usually produced small, poor quality grain in comparison to the check.

The average percent germination was 68 for the seed from the check plants and 62 for the seed from the treated plants. The average height of the check and treated plants at four weeks of age was 36 and 34 cm respectively. There were no visual morphological abnormalities in any of the seedlings such as characterize plants treated with dalapon. From the data and observations it was concluded that there was no carryover of dalapon in corn.

*Root versus shoot absorption of dalapon.* The results of this experiment are given in Table 3. Both dry weight and height data showed that dalapon was more effective when applied to the roots as compared to shoots. The difference in response between root treated and shoot treated plants may be partially explained since

*Table 3.* The average growth and dry weight of 4 corn plants in each of 3 tests that had their roots or shoots treated with dalapon as compared with a check.

| Test dates | Growth in cm | | | Shoot dry weight in gm | | | Root dry weight in gm | | |
|---|---|---|---|---|---|---|---|---|---|
| | Check | Roots treated | Shoots treated | Check | Roots treated | Shoots treated | Check | Roots treated | Shoots treated |
| Sept. 9... | 47.5 | 5.0 | 30.8 | 5.28 | 1.71 | 3.25 | 2.28 | 0.74 | 1.34 |
| Oct. 5... | 56.2 | 11.7 | 48.7 | 6.86 | 3.91 | 4.84 | 2.29 | 1.63 | 1.22 |
| Dec. 30.. | 47.5 | 3.2 | 30.0 | 4.40 | 1.04 | 3.47 | 1.61 | 0.33 | 1.50 |
| Av..... | 50.4 | 6.7 | 33.2 | 5.51 | 2.22 | 3.85 | 2.06 | 0.90 | 1.35 |

two different absorption-translocation mechanisms are involved. The herbicide was absorbed by the leaves through a hard-to-wet cutinized surface but there is no similar cutinized barrier in the roots. Furthermore, translocation after absorption would probably be through the phloem after entering the leaves and through the xylem from the roots.

*Response of different hybrids.* The responses of eleven corn hybrids to dalapon are given in Table 4. Pfister 631 and Pioneer 309A were affected the most; the least affected were U.S. 13, Dixie 29, and Coker 811. The variation among the intermediates was relatively small, and there was no consistent order of response at the various times of measurement. The variation among hybrids was not associated with period of maturity.

*Table 4.* The average height of 11 corn hybrids 2 and 4 weeks after treatment with 2 lb/A of dalapon when 3 weeks old.

| Hybrids in order of maturity | Average height expressed as per cent of the check | |
|---|---|---|
| | 2 weeks after treatment | 4 weeks after treatment |
| 1—Minhybrid 611 | 64 | 52 |
| 2—Wisconsin 642 | 63 | 58 |
| 3—Funks G-50 | 63 | 52 |
| 4—U. S. 13 | 66 | 60 |
| 5—Pfister 631 | 50 | 34 |
| 6—Pioneer 309A | 54 | 30 |
| 7—Dixie 29 | 66 | 75 |
| 8—Mosby | 58 | 55 |
| 9—Dixie 82 | 58 | 58 |
| 10—Coker 811 | 68 | 73 |
| 11—Dixie 18 | 57 | 55 |
| LSD—5 pct level | — | 22.3 |

*Effects of age, spray date, and rate on toxicity of dalapon to Johnsongrass.* The effects of the various treatments of dalapon on Johnsongrass are given in Table 5. Dalapon decreased the dry weight of the young plants in the first cutting but did not affect the older plants which were mature when sprayed. The effect of dalapon was quite evident on all ages at the second cutting. The maximum effect occurred on plants 3 and 6 weeks old, and the minimum effect on plants 9 and 12 weeks old.

*Table 5.* Second cutting yield of Johnsongrass. The first cutting was made 2 weeks after treatment with dalapon and the second cutting 3 weeks after the first. Average of four replications.

| Age when sprayed | Yield of second cutting as per cent of the check following treatment with dalapon at | |
|---|---|---|
| | 5 lb/A | 20 lb/A |
| 12 weeks | 77 | 25 |
| 9 weeks | 48 | 38 |
| 6 weeks | 21 | 3 |
| 3 weeks | 7 | 1 |

## SUMMARY

1. The toxicity of dalapon to corn was not significantly affected by the age of corn.
2. Spray dates influenced the toxicity of dalapon to corn.
3. Dalapon greatly decreased the height of corn. This decrease resulted from a shortening of the internodes rather than a decrease in number of nodes.

4. Corn hybrids varied significantly in their susceptibility to dalapon. This difference was not correlated with the period of maturity of the hybrids.
5. Dalapon became less toxic to Johnsongrass as the shoots grew older.
6. There was no indication that dalapon was carried over to the next generation in seed corn produced on plants that were treated when 1 to 6 weeks old.
7. Absorption and/or translocation of dalapon by corn roots was more efficient and less variable than by shoots.

## LITERATURE CITED


1. ANDERSON, L. E. Chemical control of Johnsongrass. Proc. NCWCC 13:32. 1956.
2. CARVER, W. A. A genetic study of certain chlorophyll deficiencies in maize. Genetics 12:415–440. 1927.
3. ENGLE, D. R., and MCILRATH, W. J. Germination of seed harvested from cotton plants damaged by 2,4–D. Texas Agricultural Experiment Station. Prog. Rept. 1394. 1951.
4. ENNIS, W. B., JR. Response of corn to 3–amino–1,2,4–triazole. Proc. SWC 9:71–79. 1956.
5. HAUSER, E. W., and THOMPSON, J. T. A study of the absorption and translocation of several chemicals in Johnsongrass, and an evaluation of their effectiveness for its control under field conditions. Weeds 7:20–33. 1959.
6. ———. Progress report on control of established Johnsongrass with chemicals and cropping. Proc. SWC 9:190–197. 1956.
7. HOAGLAND, D. R., and ARNON, D. I. The water-culture method for growing plants without soil. California Agricultural Experiment Station Circular 347. 1950.
8. KEMPTON, J. H. A brachytic variation in maize. U. S. Dept. Agr. Bul. 925. 1921.
9. MILLER, J. H., WILKERSON, J. A., and WALHOD, V. T. Carry over response of 2,4–dichlorophenoxyacetic acid and 2–methyl–4–chlorophenoxyacetic acid through seed of cotton. Proc. SWC 11:72–73. 1958.
10. RIES, S. K. The effects of fertilizer applications on quackgrass control with dalapon treatments before planting vegetables. Proc. NCWCC 13:60–61. 1956.
11. STANDIFER, L. C., and ENNIS, W. B. Developmental studies on sodium 2,2–dichloropropionate as a herbicide for Johnsongrass. Proc. SWC 9:183–189. 1956.
12. VENGRIS, J. Chemical control of quackgrass. Proc. NEWCC 10:241–245. 1956.

# Experiments with Herbicides in Soils

A. S. Crafts and Harold Drever[1,2]

Because all agricultural chemicals applied to plants eventually reach the soil, and because many herbicides are applied directly to the soil for absorption through plant roots, it is desirable to test the persistence of these reagents in soils of varied types. Many such tests have already been conducted (1, 3, 4, 5, 6, 8, 9, 10, 11). Additional studies will be necessary as new phytotoxic chemicals are discovered. In this paper tests on some of the herbicides which have been studied during the past decade are described. Most of these herbicides are already in extensive use and much information has already been obtained relative to their reaction in soils. The data included here are submitted in an effort to round out the available information, particularly as related to long time effects of the herbicides in soils.

Literature was reviewed on the persistence of the following herbicides: sodium salt of trichloroacetic acid (TCA), sodium salt of 2,2–dichloropropionic acid (dalapon), isopropyl *N*–phenylcarbamate (IPC), isopropyl *N*–(3–chlorophenyl)carbamate (CIPC), isopropyl *N*–(3–chloro–6–methylphenyl)carbamate (CMIPC), 2,3,6–trichlorobenzoic acid (2,3,6–TBA), 3–phenyl–1,1–dimethylurea (fenuron), and 3–(*p*–chlorophenyl)–1,1–dimethylurea (Monuron). Several investigators have reported on TCA, dalapon, IPC, CIPC, and CMU. Only a limited number of reports are available on CMIPC and fenuron and no reports could be found at this time on TBA.[3]

A number of investigators (1, 2, and 12) are in agreement that inactivation of some of these herbicides is greater in heavier soil or soils high in organic matter than in lighter soils or soils low in organic matter. Factors contributing to this effect may be greater microbiological population or conditions favoring their proliferation and activity, such as high temperature, adequate moisture, and amount of organic matter in the soil (1, 2, 3, 6, 8, 9, 10, 11 and 12). Other factors contributing to the inactivation of the herbicides might include magnitude of fixation to soil colloids (3, 4), volatilization (12), hydrolysis (7), and pH or liming of soils (6).

In general TCA, dalapon, and IPC, under favorable conditions, are persistent in soils for short periods of time, CIPC and CMIPC for a longer period, and the substituted ureas for much longer periods.

In view of the many factors that may influence any one experiment, the results of this particular investigation are offered for study and as supplementary information in the hope that they may be used

---

[1]Professor of Botany and Laboratory Technician, University of California, Davis, California.

[2]The writers wish to acknowledge the valuable help of T J. Sheets in the preparation of the manuscript for publication; Dr. P. B. Kaufman, Mr. W. A. Harvey and Dr. O. A. Leonard set up the experiments reported in Tables 1 and 2.

[3]Reports from Phillips on TBA appear in NCWCC 15th Proceedings, 1958, and in weeds 7:284–294. 1959. Editor.

as an aid in eventual generalizations with regard to the relation of chemical structure to the persistence of herbicides in soils.

## MATERIALS AND METHODS

The herbicides employed in these comparative toxicity studies were TCA, dalapon, IPC, CIPC, CMIPC, 2,3,6–TBA, fenuron, and monuron.

Three soils were used: Yolo fine sandy loam, Yolo clay loam, and Egbert loam. Yolo fine sandy loam and Yolo clay loam are recent alluvial soils from sandstones and shales of the Coast Range mountains of California. The clay of these soils is high in montmorillonite. Egbert loam is a mixed organic soil composed of clay from the Sacramento basin with a high content of organic matter derived from peat.

The biological methods used were those employed by Crafts (13). Briefly they consist of placing 500 grams of air dry soil in a can that has no provision for drainage. The herbicide is added either directly to the air dry soil, mixed thoroughly and a predetermined amount of water added to bring the soil to field capacity, or by mixing the appropriate amount of a stock solution of the herbicide with the predetermined amount of water necessary to bring the soil to field capacity. Seeding is accomplished by placing thirteen Kanota oat seeds in the surface of the soil in each can with the germ end firmly thrust into the soil. The plants are thinned to 10 and watered periodically to weight. After four weeks' growth the plants are harvested and the fresh weight of the plant growth above the surface of the soil recorded. After a drying period of four weeks the plant material is placed back in the can, covered with the pulverized soil and reseeded. The fresh weight data are used as a measure of toxicity.

The concentrations of the herbicides used were 0, .1, .2, .4, .8, 1.6, 3.2, 6.4, 12.8, 25.6, 51.2, 102.4, 204.8, 409.6 and 819.2 ppm by weight of the molecular equivalent of the herbicide in 500 grams of the air dry soil.

The results are based on figures derived from the fresh weights of the growth above the soil surface. All experiments were replicated 3 times. The values presented in Tables 1 and 2 were obtained by plotting average fresh weights of each run against the logarithm of dose and taking the dosage at the 50 percent growth point. The number of runs required to reduce activity of each chemical to the 50 percent growth level was used in formulating Tables 1 and 2.

## RESULTS

The first experiment was a comparative study of the persistence of IPC, CIPC and monuron in the three California soils, Yolo fine sandy loam, Egbert loam, and Yolo clay loam. Table 1 shows the results of this test. IPC was inactivated very rapidly in all three soils. At the end of three runs there was little or no toxicity to oat plants even at the very high concentrations. CIPC was inactivated in

*Table 1.* Persistence of herbicides in soils. Number of runs required to reduce the activity level of the herbicide to permit growth equal to 50% of control or more.

| Conc. ppmw | IPC | | | CIPC | | | Monuron | | |
|---|---|---|---|---|---|---|---|---|---|
| | YFSL | EL | YCL | YFSL | EL | YCL | YFSL | EL | YCL |
| .1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| .2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| .4 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 |
| .8 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 |
| 1.6 | 2 | 1 | 2 | 2 | 1 | 1 | 4 | 1 | 3 |
| 3.2 | 2 | 1 | 2 | 2 | 1 | 2 | 7 | 2 | 4 |
| 6.4 | 2 | 2 | 2 | 2 | 2 | 2 | 11 | 3 | 9 |
| 12.8 | 2 | 2 | 2 | 2 | 2 | 2 | 17 | 12 | 17 |
| 25.6 | 2 | 2 | 2 | 2 | 2 | 2 | >22 | 17 | >24 |
| 51.2 | 2 | 2 | 2 | 3 | 3 | 3 | >24 | >21 | >24 |
| 102.4 | 2 | 2 | 2 | 4 | 6 | 4 | >24 | >24 | >24 |
| 204.8 | 2 | 2 | 2 | 5 | 9 | 5 | >24 | >24 | >24 |
| 409.6 | 3 | 2 | 3 | 15 | 11 | 7 | >24 | >24 | >24 |
| 819.2 | 3 | 3 | 3 | 18 | 14 | 15 | >24 | >24 | >24 |

all three soils rather rapidly. Monuron was very persistent. Even after twenty runs each of which included a thirty day growing period and a thirty day drying period, toxicity was acute above 12.8 ppmw in the two Yolo soils and above 25.6 ppmw in the Egbert loam.

A comparison of the relative persistence among soil types can also be made from Table 1. Initial toxicity of IPC was greatest in the Yolo fine sandy loam and least in Egbert loam. IPC was slightly more persistent in the two Yolo soils after 2 runs. After three runs the herbicide was inactivated in all three soils at the highest concentration. Initial toxicity of CIPC among soil types was in the same order as for IPC. At the end of two runs 25.6 ppmw and above were still toxic in all three soils. At the higher concentrations inactivation occurred more rapidly in Egbert loam, requiring 14 runs as compared to 15 runs for Yolo clay loam and 18 runs for Yolo fine sandy loam. Initial toxicity of monuron followed the same order as IPC and CIPC, being greatest in Yolo fine sandy loam, lower in Yolo clay loam and lowest in Egbert loam. Inactivation at the 6.4 ppm conc. level was completed after three runs in Egbert loam, after nine runs in Yolo clay loam, and after eleven runs in Yolo fine sandy loam.

The second experiment was another comparative study of the persistence of seven herbicides, TCA, dalapon, CIPC, CMIPC, 2,3,6–TBA, fenuron, and monuron, in three California soils, Yolo fine sandy loam, Yolo clay loam, and Egbert loam (Table 2).

Initial toxicity in order of increasing toxicity would place the herbicides in the following order: fenuron and monuron, CIPC, dalapon and TCA, CMIPC, and 2,3,6–TBA. It should be mentioned here that Table 2 is based on fresh weight of plants, and with 2,3,6–TBA, even though the weight of the plants was not inhibited too severely, pronounced symptoms (rolling of leaves) occurred at the low concentrations. This did not occur with any of the other herbicides tested.

Table 2 indicates the herbicides in order of most rapid inactiva-

*Table 2.* Persistence of herbicides in soils. Number of runs required to reduce the activity level of the herbicide to permit growth equal to 50% of control or more. Experiment started in August, 1953.

| Conc. ppmw | TCA | | | Dalapon | | | CIPC | | | CMIPC | | | 2,3,6-TBA | | | Fenuron | | | Monuron | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | YFSL | EL | YCL | YFSL | EL | YCL | YFSL | EL | YCL | YFSL | EL | YCL | YFSL | EL | YCL | YFSL | EL | YCL | YFSL | EL | YCL |
| .4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| .8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 |
| 1.6 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 5 | 1 | 4 |
| 3.2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 10 | 5 | 7 |
| 6.4 | 2 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 9 | 4 | 12 | 12 | 12 |
| 12.8 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 7 | 18 | 5 | >20 | >20 | >20 |
| 25.6 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 4 | 1 | 3 | 2 | 1 | 1 | 9 | >20 | 8 | >20 | >20 | >20 |
| 51.2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 5 | 3 | 6 | 5 | 5 | 5 | 3 | 5 | 12 | >20 | 12 | >20 | >20 | >20 |
| 102.4 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 6 | 3 | 10 | 9 | 7 | 10 | 5 | 10 | 16 | >20 | 14 | >20 | >20 | >20 |
| 204.8 | 3 | 2 | 2 | 4 | 3 | 3 | 5 | 8 | 4 | 16 | 12 | 13 | 18 | >20 | 16 | >20 | >20 | 16 | >20 | >20 | >20 |
| 409.6 | 3 | 2 | 3 | 6 | 5 | 6 | 9 | 11 | 8 | 18 | 13 | 13 | >20 | >20 | >20 | >20 | >20 | >20 | >20 | >20 | >20 |
| 819.2 | 3 | 2 | 3 | 8 | 7 | 6 | 18 | 13 | 15 | >19 | 16 | >19 | >20 | >20 | >20 | >20 | >20 | >20 | >20 | >20 | >20 |

>20 = greater than 20.

tion as follows: TCA, dalapon, CIPC, CMIPC, 2,3,6–TCB, fenuron, and monuron.

A comparison of inactivation among the three soil types can also be made from Table 2. TCA was inactivated more readily in Egbert loam than in the two Yolo soils. Dalapon was most persistent in Yolo fine sandy loam, least persistent in Yolo clay loam, and intermediate in Egbert loam. CIPC showed the same relationship as TCA inasmuch as inactivation occurred sooner in Egbert loam than in the two Yolo soils. CMIPC remained more persistent in Yolo fine sandy loam, intermediate in Yolo clay loam, and least persistent in Egbert loam. Both carbamates seemed to experience periods of relative stability interspersed with periods of rapid breakdown. 2,3,6–TBA appeared quite persistent in all three soils. Breakdown occurred at low concentrations during the first seven runs, in the Egbert loam. After the seventh run, however, the toxicity remained fairly uniform in all three soils. Fenuron appeared unusually persistent in Egbert loam, intermediate in Yolo fine sandy loam, and least persistent in Yolo clay loam. There was little difference in the rate of inactivation of monuron among the three soils.

## DISCUSSION

The principal value of the studies described is the comparison of toxicity and breakdown.

These studies give a comparative idea of the types of persistence encountered in the use of herbicides and so are valuable in assessing the usefulness of the chemicals on non-agricultural lands and in anticipating possible problems of soil residues on crop land. Because of the extreme persistence of the urea herbicides, it seems evident that they should be used with a great deal of caution on crop lands.

This caution applies as well to the symmetrical triazines and other herbicides of similar persistence in soils. Furthermore, in deep-rooted crops such as trees, vines and alfalfa it should be kept in mind that as these materials are leached into lower soil strata they find themselves in low $O_2$, high $CO_2$ conditions where microbial activity is much less than in the top soil, and also in many situations the subsoils are heavier and less well drained. These conditions all contribute to slower breakdown. It might be well to recall that the use of lead arsenate in orchards of the Pacific Northwest went on for 25 years or more before difficulties were experienced. Without wishing to be alarmists, the writers would like to point out some of the possible hazards that may lie ahead where persistent soil sterilants are used on crop lands. On the other hand these chemicals should prove very valuable for sterilization on non-agricultural land and this in itself constitutes a very large market.

Because only one test plant was used, the results presented here are limited, for, as is well known, each chemical tested has specific selectivities when many species are used. For example TCA, dalapon, and the carbamates are all somewhat more toxic to grass than to broad-leaved weeds. On the other hand TBA is known to be especially toxic to beans. Asparagus and spinach tolerate moderate

amounts of monuron but tomatoes are very sensitive. Because of such selectivities the use of preemergence chemicals applied through the soil on crop land requires careful testing with the crops involved. Such tests must be run in the field under the climatic and soil conditions encountered in growing the crops.

Many new herbicidal chemicals are appearing and each of these will require careful study with respect to persistence. Usually each new material has come from a screening program conducted by the manufacturer and so some information is usually available at the time of introduction. However this is often limited by the type of screening involved. More extensive tests, particularly with respect to crop species, are usually justified and these should cover all the aspects from screening to final use. The methods used in these and previous tests are practical, speedy, and require a minimum of labor.

## SUMMARY

A study of the persistence of several herbicides in three California soil types was conducted using Kanota oats as the indicator plant. The study was divided into three phases, (1) comparative initial toxicity, (2) comparative inactivation between herbicides, and (3) comparative inactivation between soil types.

The initial toxicity of the herbicides in order of decreasing toxicity was as follows: fenuron and monuron, CIPC, dalapon and TCA, CMIPC, and TBA.

Comparative inactivation among herbicides as shown by this experiment, in order of most rapid to slowest inactivation, was as follows: TCA, dalapon, CIPC, CMIPC, TBA, fenuron, and monuron. From this experiment no close correlation could be found between rate of inactivation and type of soil.

Because of their persistence in soils many herbicides should be used with caution on crop lands. The substituted ureas, the symmetrical triazines and all other herbicides of similar persistence in soils should be very thoroughly tested before being used on crop lands.

## LITERATURE CITED

1. OGLE, R. E., and WARREN, G. W. Fate and activity of herbicides in soils. Weeds 3:257–273. 1954.
2. BARRONS, K. C., and HUMMER, R. W. Some basic herbicidal studies with derivatives of TCA. Proc. SWCC 4:3–12. 1951.
3. LOUSTALOT, A. J., and FERRER, R. Studies on the persistence and movement of sodium trichloroacetate in the soil. Agron. Journal 42:323–327. 1950.
4. BLOUCH, ROGER, and FULTS, JESS. The influence of soil type on the selective action of chloro IPC and sodium TCA. Weeds 2:119–124. 1953.
5. RAI, G. S., and HAMNER, C. L. Persistence of sodium trichloroacetate in different soil types. Weeds 2:271–279. 1953.
6. HOLSTUN, T. J., JR., and LOOMIS, W. E. Leaching and decomposition of 2,2-dichloropropionic acid in several Iowa soils. Weeds 4:205–217. 1956.
7. NEWMAN, A. S., DE ROSE, H. R., and DE RIGO, H. T. Persistence of isopropyl *N*-phenylcarbamates in soils. Soil Science Vol. 66 383–397. 1948.
8. FREED, V. W., and BIERMAN, H. E. IPC and chloro IPC as representative carbamates as herbicides. Proc. WWCC. 13:21–27. 1952.

9. HILL, E. D., MCGAHEN, J. W., BAKER, H. M., FINNERTY, D. W., and BINGEMAN, C. W. The fate of substituted urea herbicides in agricultural soils. Agron. Jour. 47:93–104. 1955.
10. SHEETS, T. J., and CRAFTS, A. S. The phytotoxicity of four phenylurea herbicides in soil. Weeds 5:93–101. 1957.
11. LOUSTALOT, A. J., MUZIK, T. J., and CRUZADO, H. J. Persistence of CMU in the soil. Agr. Chem. 8(11):52, 53, 97. Nov. 1953.
12. ALDRICH, R. J. Herbicide residues in soil. Journal of Agr. and Food Chem. 1:257–260. 1953.
13. CRAFTS, A. S. Toxicity of sodium arsenite and sodium chlorate in four California soils. Hilgardia 9:459–498. 1935.

# Evidence for Hydrolysis of Esters of 2,4–D during Absorption by Plants

A. S. Crafts[1]

It has been recognized for some time that although short-chain alkyl esters of 2,4–D are very toxic, they do not translocate so well as the parent acid or the heavy esters (1). Two very plausible reasons for this are apparent: (1) These compounds, being highly lipoid soluble, dissolve readily in plant cuticle, and other lipoid phases, and tend to be held in this phase; (2) penetrating rapidly, these compounds are highly toxic to the treated leaves. This contact toxicity kills the mesophyll and fine vascular bundles of the leaf and stops translocation.

In order to evaluate the relative effectiveness of these two factors it seemed desirable to determine whether or not the esters are hydrolyzed during absorption into the leaf. The isopropyl ester of 2,4–D was tagged[2] in two locations: (1) in the carboxyl position and (2) on the alcohol chain.

Solutions of the two tagged lots were made in acetone at concentrations equivalent to 10 microcuries per ml. A solution of carboxyl-labeled 2,4–D acid in 50% alcohol with 0.1% Tween 20 was used for comparison. Solution cultured barley plants having six expanded leaves were used for the experiment. Treatment was on leaf number 3 or leaf number 6 of each plant. Volume of solution was 10 lambdas, dosage 0.1 microcurie, treatment time two days. The plants were freeze-dried and autographed as previously described (5).

Figure 1 shows the mounted plants (below) and the autographs (above) for treatment on leaf 3. On the left is shown the results of using the carboxyl labeled isopropyl ester, in the center the alcohol labeled ester, and on the right the carboxyl labeled acid. Since the alcohol label stays in the treated leaf, moving only in an acropetal direction it seems evident that it has been hydrolyzed off from the acid. The carboxyl-labeled ester residue, and the carboxyl-labeled acid both show a basipetal movement into crowns, young leaves and roots. This is evidence for phloem transport with assimilates which is as extensive as can be expected of 2,4–D* in such plants (2).

Treatments on leaf 6 are shown in Figure 2; arrangement of mounted plants, autographs, and chemicals are as in Figure 1. Again movement of the alcohol label is only acropetal; movement of the carboxyl-labeled compounds is basipetal and phloem limited.

The acropetal movement of the labeled isopropyl alcohol in these treatments seems to indicate that this alcohol is not phloem mobile. Probably movement occurs in the xylem along with the transpiration stream. The ions of the 2,4–D* acid on the other hand seem

[1]Professor, University of California, Davis, California.

[2]Synthesis of the two tagged lots of the isopropyl ester of 2,4–D was done by R. G. Powell in the Department of Agriculture, Oxford University.

readily to enter and move in the phloem. However, as in previous experience (3, 2) 2,4–D* seems to be held in active tissues and so to attain a much less extensive distribution than do such compounds as ATA*, MH*, and sugars*. Experiments using the same three tracers in cotton and *Zebrina pendula* give comparable results though somewhat less graphic.

Returning to the two causes for lack of translocation of the alkyl esters of 2,4–D, the fact that the isopropyl ester is hydrolyzed in the leaf makes the first cause less important because, after hydrolysis the ester no longer persists in the cuticle as such but the 2,4–D ion moves on across the mesophyll and into the phloem. Partition of the 2,4–D ion should be into the aqueous phase because of its polarity. This process greatly steepens the diffusion gradient from the surface inward and must necessarily hasten movement. Although

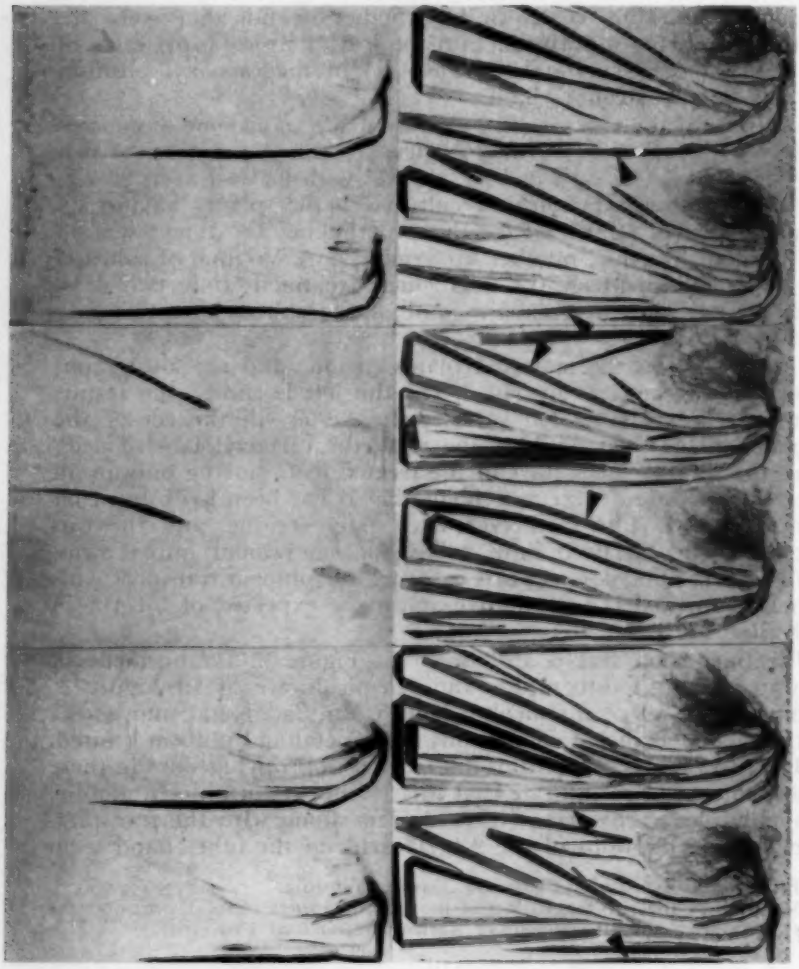


*Figure 1.* Autoradiographs (top) and mounted plants (bottom) showing the uptake and distribution of $C^{14}$ located in the carboxyl position of the isopropyl ester of 2,4–D (left); located in the alcohol chain of the isopropyl ester of 2,4–D (center); and located in the carboxyl position of 2,4–D acid (right). Treatment was on leaf number 3 of barley plants having 6 expanded leaves.

a certain residue must remain in the cuticle, it cannot account for the lack of long-distance transport observed. And the autographs show that under the conditions of this experiment the 2,4–D* ion does move as well as when the acid itself is applied.

Turning to the second cause for failure of transport it should be emphasized that the treatment used in these experiments employed a minimal dosage to avoid contact injury. Under conditions of field application a much greater dose is applied and the whole plant is covered. Under these conditions the leaves are rapidly burned and may be dead in a day or two. Probably the phloem in the latter case is rapidly injured and extensive transport prevented. This lays the stress on dosage and the rapidity of action. If failure to translocate depended upon lack of partition this could be remedied by increas-

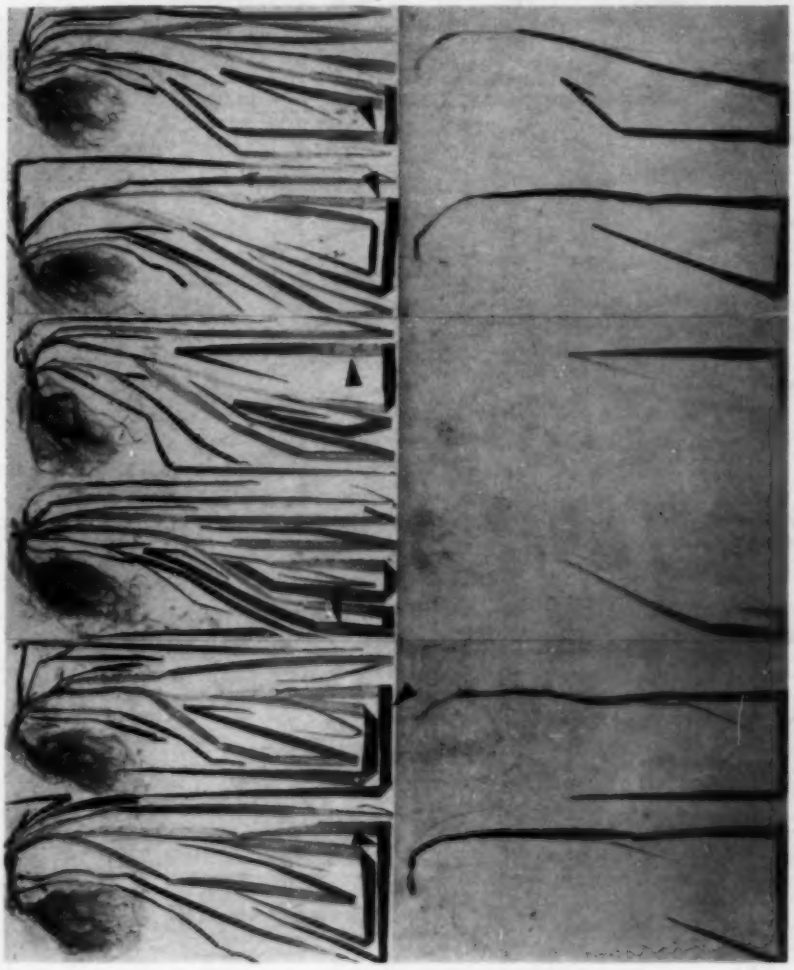


*Figure 2.* Autoradiographs (top) and mounted plants (bottom) showing the uptake and distribution of $C^{14}$ located in the carboxyl position of the isopropyl ester of 2,4-D (left); located in the alcohol chain of the isopropyl ester of 2,4-D (center); and located in the carboxyl position of 2,4-D acid (right). Treatment was on leaf number 6 of barley plants having 6 expanded leaves.

2,4-D acid (right). Treatment was on leaf number 3 of barley plants having 6 expanded leaves.

ing the dosage. If it depends on contact injury then an optimum dosage should be used; increase above the optimum would increase injury and reduce translocation. Ideally the herbicide should be applied in such a way that a maximum amount of toxicant is moved with a minimum of injury to the leaves, and to the phloem of the stems and roots.

In order to study the role of dosage in the mechanics of uptake and transport two dosage series were treated using 2,4–D* acid bearing a carboxyl label and varying dosage with constant volume in one series; varying both dosage and volume in the second.

Figure 3 shows the dosage series with volume constant. Doses

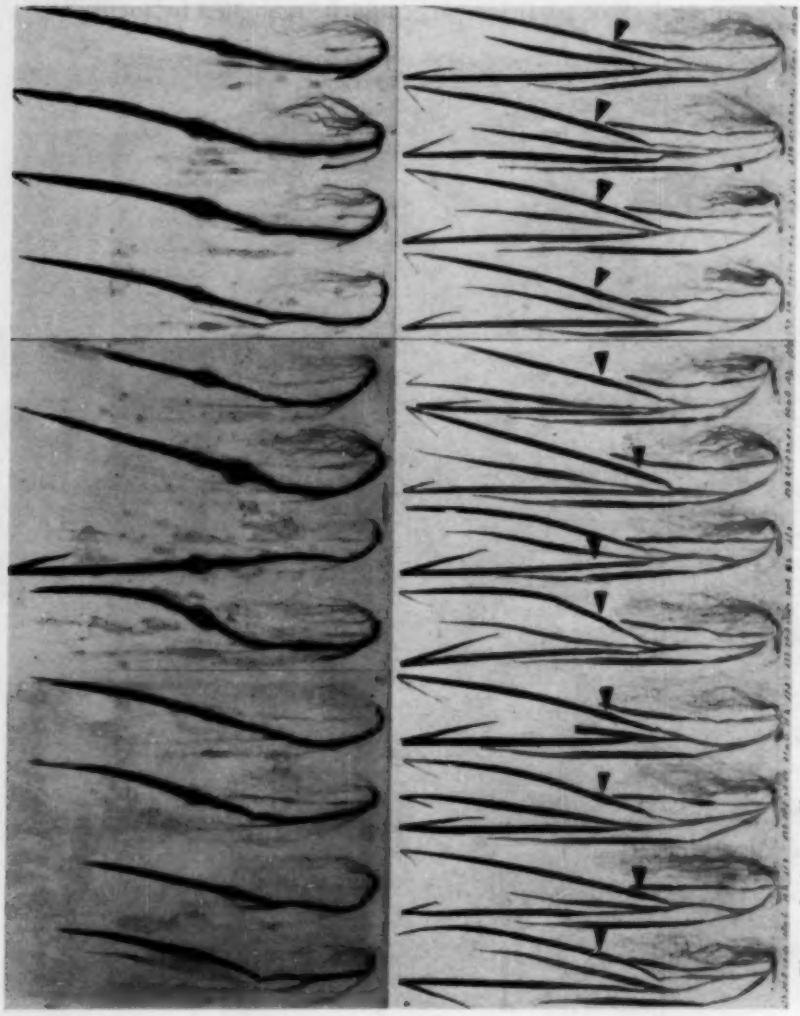


*Figure 3.* Autoradiographs (top) and mounted plants (bottom) showing the uptake and distribution of $C^{14}$ located in the carboxyl position of 2,4–D acid. Dosage series, two plants per replication, left to right 0.05 uC, 0.1 uC, 0.2 uC, 0.3 uC, 0.4 uC and 0.5 uC, all applied in the 10 lambdas per plant.

applied were 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 μc using a lot of 2,4–D* having a specific activity of 5.0 mC per mM dissolved in 50% alcohol plus 0.1% Tween 20. Treatment was on leaf number 3. As one examines the autographs he finds that more and more of the tracer reached the roots as the dosage was increased. This should follow from the fact that the initial small quantities that first enter chlorenchyma cells are retained in these cells, and only as they are saturated may more molecules move on. Thus, by the time the molecules from the higher doses have reached the crown, there remain sufficient numbers to move throughout the roots. The 0.5 μC dosage used here did not cause rapid contact injury.

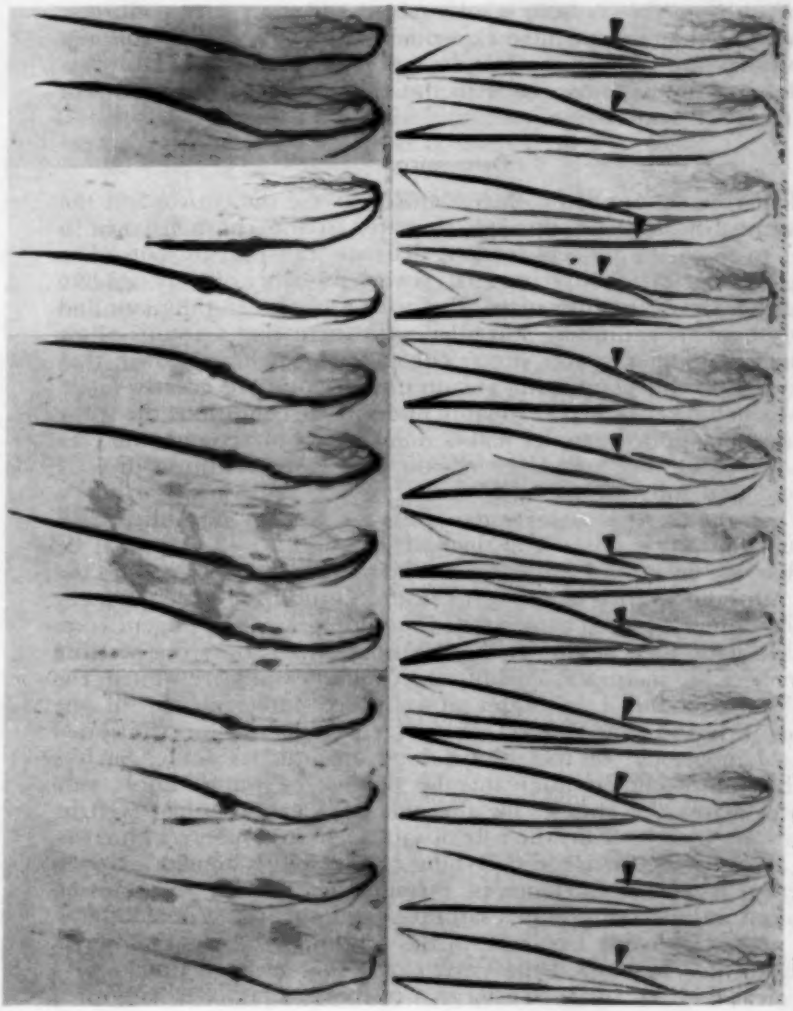


*Figure 4.* A similar dosage series to that in Figure 3 except that the volume of the applied solution as well as the dosage was varied. Two plants per treatment. Treatments, left to right, 0.05 uC in 1 λ, 0.1 uC in 2 λ, 0.2 uC in 4 λ, 0.3 uC in 6 λ, 0.4 uC in 8 λ, and 0.5 uC in 10λ.

lambdas per plant.

Figure 4 presents the dosage series in which volume also varied in proportion to dosage. Volumes were 1, 2, 4, 6, 8, 10 lambdas corresponding to 0.05, 0.1, 0.2, 0.3, 0.4, and 0.5 μC. Here it is noticeable that movement of the tracer from the lower volumes is less than where volume was held constant. Since the solvent used evaporated in less than an hour whereas the experiments lasted twenty-four hours, the differences in size of the treated spot and volume of Tween 20 probably were responsible for the greater absorption from the higher volume. This formulation dries down to a thin film with the 2,4–D* dissolved in the Tween 20. The 2,4–D* undoubtedly diffuses into and across the cuticle from this film and because it dissociates to a higher and higher degree as it moves into the sieve tubes of the phloem, the gradient is maintained and movement continues for at least the term of these experiments. The very small volumes of solvent coupled with the low dosages resulted in appreciably less 2,4–D* moving as compared with the same dosages in the constant volume of 10 lambdas.

## DISCUSSION

All herbicides applied to leaves must traverse the cuticle and the epidermis, or move in through stomates to the chlorenchyma in order to reach the phloem for long-distance transport to roots. The cuticle, either external or internal, is very probably of a sponge-like consistency with the interstices filled with water when the plant and atmosphere are saturated, and filled with increasing amounts of air as the plant suffers water stress. Zukel, et al. (6) have shown, that surrounding the plant with a saturated atmosphere greatly facilitates penetration of MH. Probably under these conditions the spray solution or applied droplet makes immediate contact with the continuous water phase and the chemical is able to diffuse directly around and into the mesophyll cells via the cell walls.

When the plant is under water stress the menisci are pulled back into the minute capillaries in the cuticle and as liquid is applied air bubbles are entrapped in the capillaries blocking movement into the leaf. Without wetting agent, spray liquid would have little tendency to enter these blocked capillaries. Containing a wetting agent compatible with the cuticle, as the solution dried down the wetting properties are increased. Possibly the capillary walls are wetted, the bubbles surrounded by water and pressed into solution in the ambient liquid, and direct contact is established for continued inward movement of the solute along an aqueous route. Such a mechanism would account for the passage of water-soluble substances across the cuticle, for the enhanced uptake when wetting agents are used, and for the role of saturated atmosphere in increasing absorption. Currier and Dybing (4) stress the stomata as ports of entry of chemicals. Once in through the stomata the solution wets cell walls that reside in a saturated atmosphere. As noted above, this makes for ready uptake into the protoplasts of the mesophyll.

Again are emphasized the virtues of a slow ordered uptake of a chemical that has to be translocated to roots to perform its normal

function. Very rapid penetration of the leaf, as in the case of the light alkyl esters of 2,4–D, results in rapid injury and failure to translocate extensively; too slow penetration, as with glycol diesters or with the tetrahydrofurfuryl ester, results in rapid recovery of the treated plants; slow ordered penetration as in the case of the butoxyethanol or propyleneglycolbutyl ether ester or the emulsifiable acid results in optimum results. Here the 2,4–D tolerance of the living mesophyll and phloem is not exceeded; movement from foliage to roots continues for several days; a lethal dose is built up in the roots and the treatment is a success.

Treatment with a single droplet of 2,4–D*, as in the experiment described here, is not designed to duplicate a spray application. It is used to investigate the nature of the mechanism involved in uptake and distribution of toxic substances during the interval between application and the onset of discrete toxicity. The low doses used cause little or no injury during the term of the experiment. They do illustrate the nature of the processes involved and suggest the means to be taken to obtain maximum results.

## ACKNOWLEDGEMENTS

The experiments reported here were performed in the Department of Agriculture, University of Oxford, where the writer spent a Sabbatical leave. Equipment and facilities required for the autoradiography were kindly provided by Professor G. E. Blackman and he and his staff were most cooperative and congenial. Certain facilities were available through AEC Contract AT(11–1) Project No. 9.

## LITERATURE CITED

1. CRAFTS, A. S. Translocation of herbicides. II. Absorption and translocation of 2,4–D by wild morning glory. Hilgardia 26(6):335–365. 1956.
2. ———. Further studies on comparative mobility of labeled herbicides. Plant Physiol. (In Press) 1959.
3. ———, and YAMAGUCHI, S. Comparative tests on the uptake and distribution of labeled herbicides by *Zebrina pendula* and *Tradescantia fluminensis*. *Hilgardia* 27(16):421–454. 1958.
4. CURRIER, H. B., and DYBING, C. D. Foliar penetration of herbicides—review and present status. Weeds 7:195–213. 1959.
5. YAMAGUCHI, S., and CRAFTS, A. S. Autoradiographic method for studying absorption and translocation of herbicides using $C^{14}$-labeled compounds. Hilgardia 28(6):161–191. 1958.
6. ZUKEL, J. W., SMITH, A. E., STONE, G. M., and DAVIES, M. E. Effect of some factors on rate of absorption of maleic hydrazide. Plant Physiol. 31(suppl.): xxi. 1956.

# Reduction of Annual Bluegrass, *Poa annua*, in Bentgrass Turf by the Use of Chemicals[1]

R. E. Engel[2] and R. J. Aldrich[3]

The great herbicidal developments of recent years give hope for chemical control of annual bluegrass, *Poa annua*, which is a major weed problem in bentgrass turf. Annual bluegrass produces an abundance of seed and quickly dominates bentgrass turf that is not growing at its optimum. Annual bluegrass might be controlled by prevention of seed set, pre-emergence control, and plant eradication. The original purpose of this study was to evaluate chemicals which offered promise of annual bluegrass control by checking seed set. However, necessity led to consideration of any promising chemical regardless of its method of control.

No formal investigations of chemical treatment of annual bluegrass were available at the time this study was initiated. In 1955 the presence of arsenicals in the soil was reported to weaken the growth of annual bluegrass (2) and in 1958 fluorophenoxyacetic acids were reported to induce sterility in annual bluegrass for four to six weeks (1). Various golf course superintendents had used sodium arsenite in an attempt to suppress annual bluegrass.

## Procedure

Preliminary field observations with herbicides applied as spring treatments in 1952 showed that 3,6–endoxohexhydrophthalic acid (endothal), maleic hydrazide, and sodium arsenite might be useful in controlling annual bluegrass. Trials were made also in September 1952, as an attempt to destroy *Poa annua* in one of its major germinating periods. Turf injury was very severe in most treatments and further work of this type was discontinued for lack of promise. Among the chemicals tried and discontinued were isopropyl*N*–(3–chlorophenyl)carbamate, isopropyl *N*–(4–chlorophenyl) carbamate, potassium cyanate, 3–(*p*–chlorophenyl)–1,1–dimethylurea, 2,4–dichlorophenoxyethyl benzoate, dichloral urea, and 2,4–D.

In 1954, a test of endothal, maleic hydrazide, and sodium arsenite was established on bentgrass fairway[4] turf which had a uniform distribution of annual bluegrass. The plots were 30 feet wide and extended across the width of the fairway. All treatments were replicated three times and were applied in 40 gallons of water per acre. The dates of treatment were April 2, 21, and May 7, 1954; April 1, 22, and May 19, 1955; April 24 and May 9, 1956; and March 25 and

[1]Cooperative investigations between the New Jersey Agricultural Experiment Station and the Crops Protection Research Branch, ARS, U.S. Dept. of Agriculture. Paper of the Journal Series, New Jersey Agric. Expt. Station, Rutgers—the State University, New Brunswick.

[2]Professor in Turf Management, Department of Farm Crops, Rutgers.

[3]Formerly Agronomist, Crops Protection Research Branch, ARS, U.S. Dept. of Agriculure; now Assistant Director, Michigan Agric. Expt. Station, East Lansing.

[4]A fairway of the Canoe Brook Country Club, Summit, N. J.

April 16, 1957. The 2-pound per acre rate of maleic hydrazide was applied the first two dates in 1954 and the first date in 1955; and the 1-pound per acre rate was applied on all dates in 1954 and the first two dates in 1955 and 1956. No further maleic hydrazide treatments were made because turfgrass injury had become intolerable.

The treatments were observed for turfgrass discoloration and seed head inhibition. The effects of treatment on turfgrass composition were determined by plant counts (point quadrat), which were made in September of 1954 and 1957.

## RESULTS AND DISCUSSION

Endothal treated plots showed a 37% increase in bentgrass the first season (Table 1) and a 55% increase at the close of the fourth season over the check. The corresponding reduction in annual bluegrass was 37% and 62%. This chemical appeared to suppress annual bluegrass by contact action on the plants. Discoloration of annual bluegrass was mild to severe while discoloration of the bentgrass was slight under the conditions of this test. Clover was essentially eliminated from the endothal plots by the first season's treatments.

Sodium arsenite plus 2,4–D gave 15% and 28% increase in bentgrass over the check in the first and fourth seasons, respectively. The corresponding reduction in annual bluegrass was 33% and 40%. The discoloration produced by the sodium arsenite plus 2,4–D treatment was mild to moderate. This treatment gave a 32% reduction in clover over the check as a result of the first season's treatments. Further trial with this treatment at a higher rate of sodium arsenite is worthy of consideration.

*Table 1.* Control of Poa annua obtained with chemicals applied to bentgrass fairway turf. Summit, New Jersey. 1954–1957.

| Chemical | Rate, lb/A | Turf composition—per cent[a] | | | | |
|---|---|---|---|---|---|---|
| | | Bentgrass | | Poa annua | | Clover[b] |
| | | 1954 | 1957 | 1954 | 1957 | 1954 |
| Check | — | 50 | 52 | 36 | 34 | 10 |
| Endothal | ½ | 68 | 81 | 24 | 13 | 1 |
| Sodium arsenite + 2,4-D | 1 + ¼ | 57 | 67 | 24 | 21 | 7 |
| Maleic hydrazide | 1 | 35 | —[c] | 32 | —[c] | 25 |

[a]The difference between the totals and 100 represent plant species such as *Poa trivialis*, *Poa pratensis*, crabgrass, and clover (1957 only).

[b]Clover readings were unavailable in 1957 because general treatment of the entire fairway was necessary prior to 1957.

[c]Treatments discontinued prior to 1957.

The maleic hydrazide treatment at a rate of 1 pound per acre produced a 29% reduction in bentgrass and a 12% reduction in annual bluegrass as compared with the check. However, a clover increase of 142% over the check was also observed. This suggests that the grasses were less competitive or deteriorated as a result of maleic hydrazide treatment.

The production of annual bluegrass seedheads was greatly reduced by maleic hydrazide treatment, and it was hoped this result would

outweigh the harmful effect which suppressed the grasses and enabled clover to flourish. However, the turf quality of the plots receiving this treatment was reduced until it was necessary to discontinue this chemical.

This study demonstrated that any treatment which destroys existing annual bluegrass plants is unsatisfactory unless there is sufficient bentgrass to close the cover rather quickly or bentgrass can be established promptly. Also, the season of herbicidal treatment produces profound differences. The severe injury from most fall applications was in contrast to the slight spring injury. Also, the early spring treatments used in these tests gave some of the most consistent performances observed with turf herbicides.

## Summary

Eleven chemicals were tried in spring and fall treatments for annual bluegrass, *Poa annua,* control. Among these, endothal, maleic hydrazide, and sodium arsenite plus 2,4–D as spring treatments offered promise. These chemicals were applied as replicated treatments to bentgrass fairway turf containing about one-third *Poa annua* in early spring of each year from 1954 through 1957. The influence of these treatments was measured by plant counts with a point quadrat in September of 1954 and 1957.

1. The endothal and sodium arsenite plus 2,4–D treatments produced reductions in annual bluegrass as compared with the check of 37% and 33% during the first season and 62% and 40%, respectively, by the fourth season. During this period the bentgrass increased 55% and 28%, respectively, over the check.

2. Two to three applications of ½ pound of endothal per acre applied at approximately 2-week intervals beginning with the start of early spring growth gave consistently good reduction of annual bluegrass. This treatment also gave good clover control.

3. Two to three treatments of 1 pound of sodium arsenite plus ¼ pound of 2,4–D at 2-week intervals beginning at the start of early spring growth gave a significant reduction in annual bluegrass.

4. Maleic hydrazide reduced the number of annual bluegrass seedheads, but also seriously reduced the bentgrass content of the turf and allowed an increase of clover which forced discontinuance of this treatment after two years.

## Literature Cited

1. Anderson, Burton R., and McLane, Stanley R. Control of annual bluegrass and crabgrass in turf with fluorophenoxyacetic acids WEEDS 6:52–58. 1958.
2. Daniel, W. H. *Poa annua* controls with arsenic materials. Golf Course Reporter 23:5–8. 1955.

# Some Effects of Amitrol on the Respiratory Activities of *Zea mays*

C. G. McWhorter[1] and W. K. Porter[2]

Amitrol (3–amino–1,2,4–triazole) has received considerable attention in recent years as a herbicide and defoliant. This material was noted to have growth-inhibiting and defoliating properties by Hall et al. (1) in 1952. Hall et al. (2) reported that amitrol caused chlorophyll destruction under certain conditions and that chlorophyll synthesis was impaired in tissues formed at the time of, or subsequent to, absorption of the chemical. These workers also reported that cotton treated with amitrol showed a loss approximately 50 percent of the original reducing sugars and sucrose. Herbert and Linck (4) have reported an initial increase in the rate of respiration of Canada thistle following treatment with amitrol. This initial respiratory increase was followed by a decrease which was dependent upon time as well as the concentration of amitrol applied to the plants. Similar results were obtained by Miller and Hall (5) using Avena sections and cotton leaf discs. Heim et al. (3) found that amitrol caused decreases in catalase activity of certain plants. Reduction of chlorophyll content and catalase activity were obtained following application of amitrol to leaves of potato, barley, and sunflower. In experiments reported in a more recent paper by these workers (6), amitrol caused in vitro inhibition of catalase activity.

Using amitrol $-5C^{14}$, Rogers (7) demonstrated that this material tends to accumulate in the younger leaves of Canada thistle plants. Relatively low rates of amitrol were toxic to Canada thistle and soybean plants but not to Johnson grass. Rogers postulated that these differences were not due to translocation but that the position of the meristematic tissue in grasses precluded accumulation of toxic quantities of amitrol.

Rogers (8) reported that chlorosis resulting from the application of sublethal rates of amitrol to corn was due to a lack of chloroplasts rather than some effect on the chlorophyll per se.

## Methods and Materials

Corn plants (var. Dixie 18) were grown in pots containing sand and the pots were flushed with Hoagland nutrient solution adjusted to pH 5.4 on alternate days. If chlorotic plants were desired, pots containing 4- or 5-day-old corn seedlings were treated with Hoagland nutrient solution which contained 80 mg/L of amitrol. Unless otherwise stated, all plants used in the study were 11 to 12 days old at time of harvest. Although the light intensity varied greatly, greenhouse light intensities were generally above 3000 foot candles

[1]Formerly Research Assistant, Louisiana State University, Baton Rouge, Louisiana, and now Plant Physiologist, Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture, Delta Branch Experiment Station, Stoneville, Mississippi.

[2]Associate Professor, Louisiana State University, Baton Rouge, Louisiana.

and often reached 10,000 foot candles. Greenhouse temperatures generally ranged from 30–35°C. In addition to plants grown under greenhouse conditions, some plants used in this study were grown in constant temperature rooms which were operated at 20° and 30°C. Light was supplied by fluorescent and incandescent light bulbs and the light intensity in each room was approximately 200-foot candles.

Homogenates of both control and chlorotic tissues were prepared by homogenizing a sample of leaf tissue in potassium phosphate buffer in a semi-micro Waring blendor. Resulting hemogenates were strained through cheesecloth to remove the crude fraction. Homogenates to be assayed for cytochrome oxidase were prepared using potassium phosphate buffer of pH 7.0. All other homogenates were prepared in potassium phosphate buffer of pH 5.85.

Respiratory activity of whole tissue and homogenates was determined using a Warburg respirometer and conventional methods described in Umbriet et al. (9). Duplicate flasks were used for each treatment. Flasks containing whole leaf tissue received 2.0 ml of a buffer solution which was 0.02 M and 0.20 M with regard to sucrose and potassium phosphate respectively. For estimation of enzyme activity in homogenates, an aliquot of homogenate was added to the main compartment of a Warburg flask and the appropriate substrate added to the side arm of the flask. As the result of several initial experiments, 0.25 M ascorbic acid, $2 \times 10^{-4}$ M cytochrome C or 0.12 M catechol was used as the substrate in the estimation of ascorbic acid oxidase, cytochrome oxidase, and polyphenol oxidase respectively. Paraphenylenediamine was used to reduce the cytochrome C. All substrates were adjusted to the appropriate pH shortly before addition to Warburg vessels.

In some initial experiments amitrol was applied to detached corn leaves by surface treatment and by vacuum infiltration. Vacuum infiltration was accomplished by immersing the leaves in a beaker of amitrol solution, placing the beaker in a vacuum desiccator, and applying a vacuum with a water suction for 10 minutes. The vacuum was then slowly released, reapplied for 10 minutes and again slowly released. The tissue was then blotted and handled as control tissue.

## RESULTS AND DISCUSSION

The effect of amitrol on detached corn leaves was studied by vacuum infiltration and/or addition of amitrol to the leaf surface. The respiration of tissue so treated was studied for periods up to 4 days, but no appreciable change was found that could be attributed to amitrol treatment. When amitrol effected a difference in respiration, it was a slight reduction.

To determine the effect of amitrol on the respiration of growing plants a solution of amitrol was used to flush the root system of greenhouse grown corn plants. Tissue harvested from these plants twenty-four hours after application of the chemical had an oxygen uptake that was approximately 20 percent higher than that of

untreated plants. Approximately four days after amitrol treatment, these plants became strikingly chlorotic. Respiration experiments showed that chlorotic tissue also respired at a more rapid rate than did control tissue. The respiratory quotients of both chlorotic and control tissue approached unity which suggested that the respiratory substrate of both tissues was carbohydrates.

The results of 26 experiments conducted during the summer and fall of 1957 indicated that of the three terminal enzymes known to be present in corn tissue, ascorbic acid oxidase predominated over cytochrome oxidase and polyphenol oxidase. Activity of ascorbic acid oxidase in chlorotic tissue was generally 2- to 3-fold that of control tissue. Following a delay in this work, it was found that in corn grown during the winter, polyphenol oxidase predominated over ascorbic acid oxidase and cytochrome oxidase. Since this change probably resulted from some change in the environmental conditions under which the plants were grown, experiments were conducted to study effects of age of plants, light, and temperature on the respiration and terminal oxidation of control and amitrol-induced chlorotic tissues.

*Effect of plant age on ascorbic acid oxidase and polyphenol oxidase.*

Estimations of ascorbic acid oxidase and polyphenol oxidase were conducted in homogenates of control tissue, the green area of amitrol-treated plants, and chlorotic tissues of amitrol-treated plants over 7, 6, and 5 day periods respectively. A summary of the data obtained in these experiments is presented in Figure 1. For brevity the plotted points of the curves in Figure 1 represent only the maximal portion of the oxidation curves obtained in these experiments.

The ascorbic acid oxidase activity of control tissue remained constant through the 7-day test period. Polyphenol oxidase activity of control plants 5, 6, 7 days old was approximately 4 times as great as ascorbic acid oxidase activity in plants of the same age. As the age of plants increased to the 9th day, however, polyphenol oxidase activity dropped to a point slightly below that of ascorbic acid oxidase, and had decreased even further when the plants were 11 days old.

The oxidation curves for ascorbate and catachol in homogenates prepared from the green portion of amitrol-treated plants were strikingly similar to those obtained from control homogenates. The only exception was the polyphenol oxidase activity of 9-day-old plants.

Ascorbic acid oxidase activity of chlorotic tissue closely paralleled that of both control and treated green plants. Polyphenol oxidase, however, was considerably lower in chlorotic tissue of 7-day-old plants than in either of the other tissues, increased to a maximum in 9-day-old plants, then decreased on the 11th day to a level quite comparable to that of the other tissues.

Ascorbic acid oxidase seemed to predominate over polyphenol oxidase only in 11-day-old tissue. No large differences in ascorbic

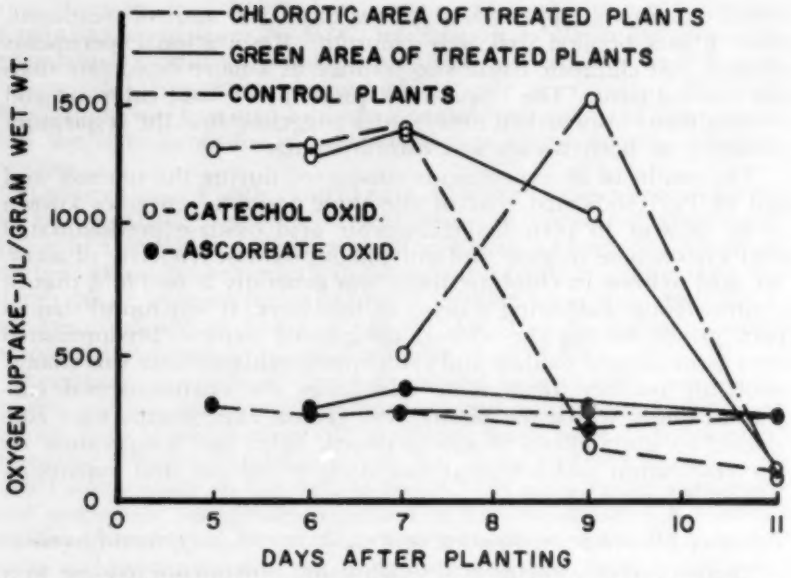



*Figure 1.* Maximal oxidation of ascorbate and catechol in corn homogenates. The oxidation of ascorbate and catechol are indicative of the activity of ascorbic acid oxidase and polyphenol oxidase respectively.

acid oxidase activity between control and chlorotic tissues were found in these experiments regardless of plant ages.

*Effect of light intensity on the activity of ascorbic acid oxidase and polyphenol oxidase in control and chlorotic plants.*

Light intensity has a profound effect on the synthesis of ascorbic acid in plants. It was felt that light might also be associated with ascorbic acid oxidase activity. This possibility was first studied by growing control and chlorotic plants under reduced light intensity in the greenhouse. Shading was accomplished by placing plants under a canopy made of cheesecloth. Plants under this canopy received only 60 percent of the light which unshaded plants received. Light intensity varied considerably, however, during the growth period due to several days of intermittently cloudy weather.

When the plants were 11 days old, they were harvested and determinations of ascorbic acid oxidase and polyphenol oxidate activities were made. Results are shown in Figure 2. The only significant change found in oxidase activity due to shading was a reduction in polyphenol oxidase activity of control tissue (Figure 2A). Shading also caused small reductions in polyphenol oxidase of chlorotic tissue (Figure 2A) and in ascorbic acid oxidase of both control and chlorotic plants (Figure 2B). Ascorbic acid oxidase activity of the chlorotic tissue was approximately twice as great as polyphenol oxidase activity but even so, the activity of this enzyme was only a

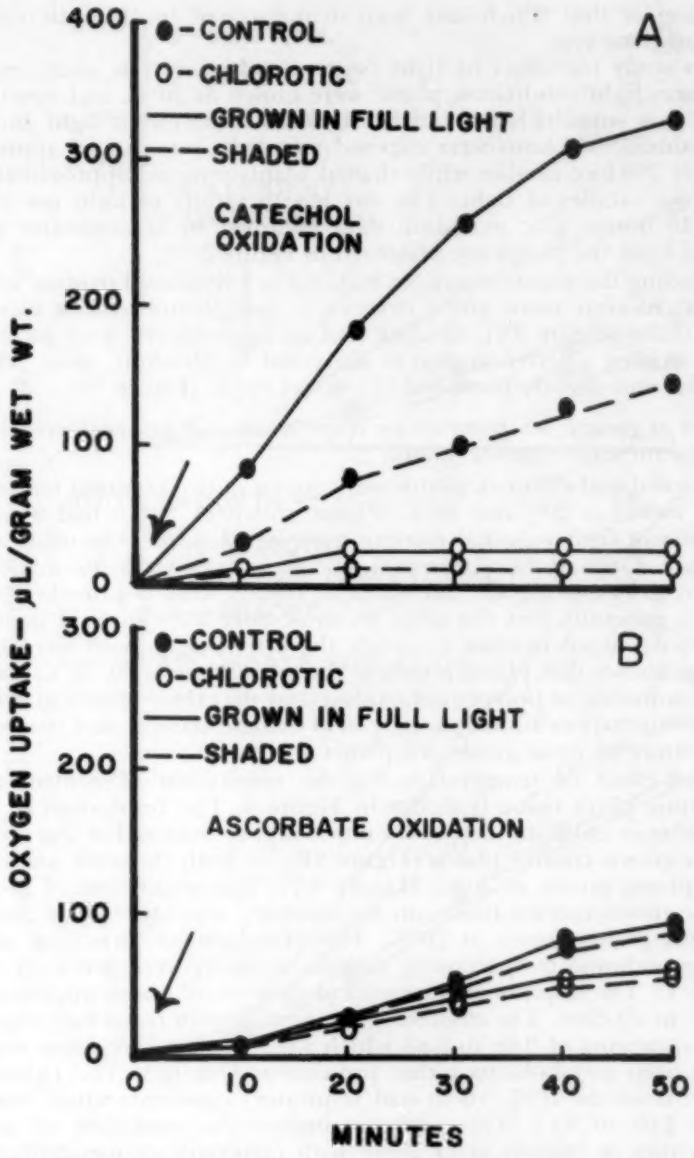



*Figure 2.* Oxidation of catechol and ascorbate in homogenates of control and chlorotic tissue grown under different light intensities in the greenhouse. Arrows indicated tip-in of substrates. The oxidation of catechol and ascorbate are indicative of the activity of polyphenol oxidase and ascorbic acid oxidase, respectively.

fraction of that which had been demonstrated in chlorotic tissue the previous year.

To study the effect of light on terminal oxidation under more uniform light conditions, plants were grown at 20°C. and constant light was supplied with incandescent and fluorescent light bulbs. The unshaded plants were exposed to a light intensity of approximately 200-foot candles while shaded plants received approximately 110-foot candles of light. The day length (hours of light per day) was 16 hours. The oxidation data obtained in homogenates prepared from the plants are presented in Figure 3.

Shading the plants caused an increase in polyphenol oxidase activity of chlorotic tissue and a decrease in polyphenol oxidase of control tissue (Figure 3A). Shading had an opposite effect on ascorbic acid oxidase activity in that it decreased in chlorotic tissue when shaded and slightly increased in control tissue (Figure 3B).

*Effect of growth temperature on respiration and terminal oxidation of control and chlorotic plants.*

Control and chlorotic plants were grown in two constant temperature rooms at 20° and 30°C. Plants grown at 20°C. had a large portion of their terminal oxidation mediated through ascorbic acid oxidate. Estimations of terminal oxidase activity were also made on plants grown at 30°C., but variable results were obtained. These plants generally had the same levels of both ascorbic acid oxidase and polyphenol oxidase although the activities of both were low. It was known that plants grown in the greenhouse at 30–35°C. had a predominance of polyphenol oxidase and that those grown at 20°C. predominately exhibited ascorbic acid oxidase activity, so a comparative study of these groups of plants was made.

The effect of temperature on the respiration of control and chlorotic plant tissue is shown in Figure 4. The respiration of the greenhouse chlorotic tissue was much higher than either the greenhouse-grown control plants (Figure 4B), or both chlorotic and control plants grown at 20°C. (Figure 4A). The respiration of greenhouse-grown control tissue, on the contrary, was lower than that of control plants grown at 20°C. This is somewhat surprising since the greenhouse temperatures, though variable, were generally 30° to 35°C. The respiratory quotients of the control plants approached unity in all cases. The chlorotic greenhouse-grown tissue had respiratory quotients of 0.81 to 0.88 which suggests that this tissue might have been metabolising either proteins and/or fats. The chlorotic tissue from the 20°C. room had respiratory quotients which varied from 1.09 to 1.14. This perhaps suggests the oxidation of small quantities of organic acids along with carbohydrate metabolism.

Ascorbate and catechol oxidation data obtained using homogenates of these plants are presented in Figure 5. These data substantiated those of previous experiments in that greenhouse plants showed a predominance of polyphenol oxidase while plants grown at 20°C. showed greater ascorbic acid oxidase activity. Thus it would seem that control plants can shift from one predominant

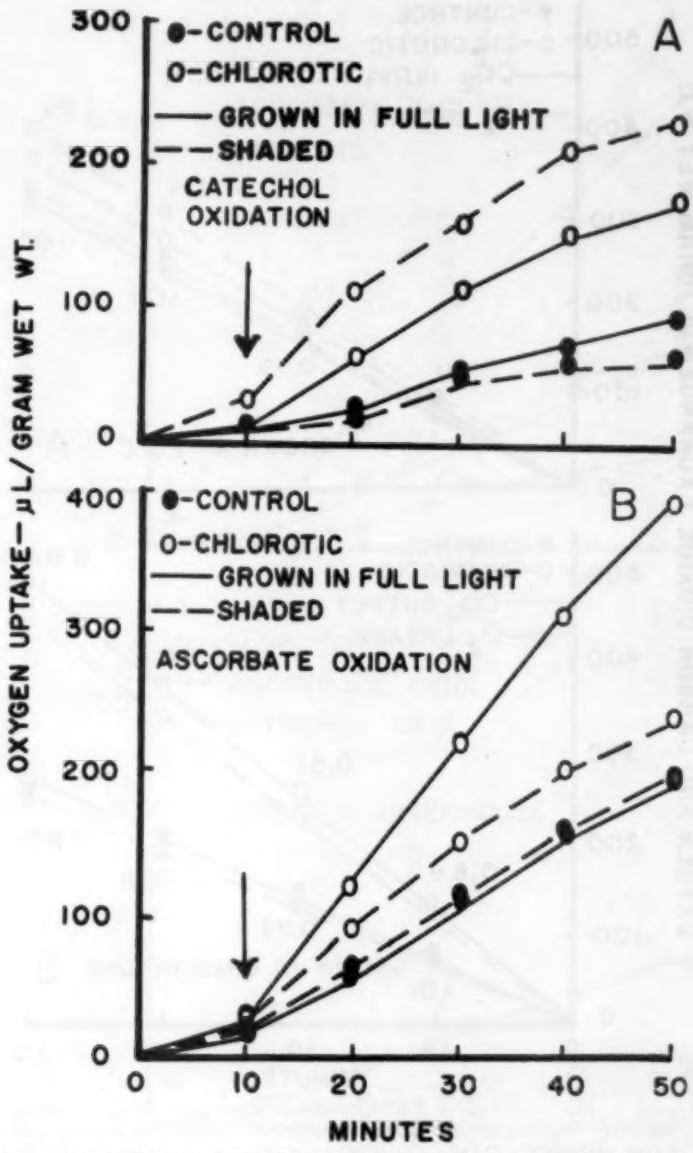



*Figure 3.* Oxidation of catechol and ascorbate in homogenates of control and chlorotic tissue grown under different light intensities of 20°C. Arrows indicate tip-in of substrates.

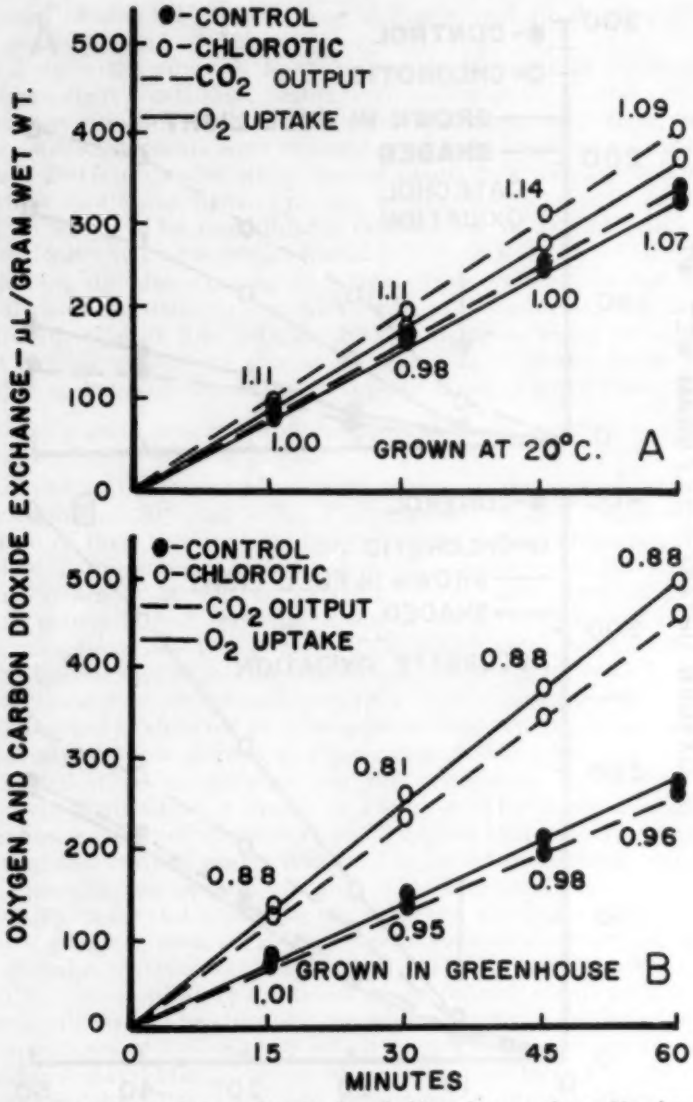



*Figure. 4.* Gas exchange of control and chlorotic corn tissue. Numbers indicate respiratory quotient. Greenhouse temperature was generally 30°–35°C.

terminal oxidase system to another without the shift being reflected in the respiratory quotient. In chlorotic tissue, however, a respiratory quotient less than unity seems to indicate the predominance of polyphenol oxidase while a respiratory quotient of unity or above seems to indicate predominance of ascorbic acid oxidase.

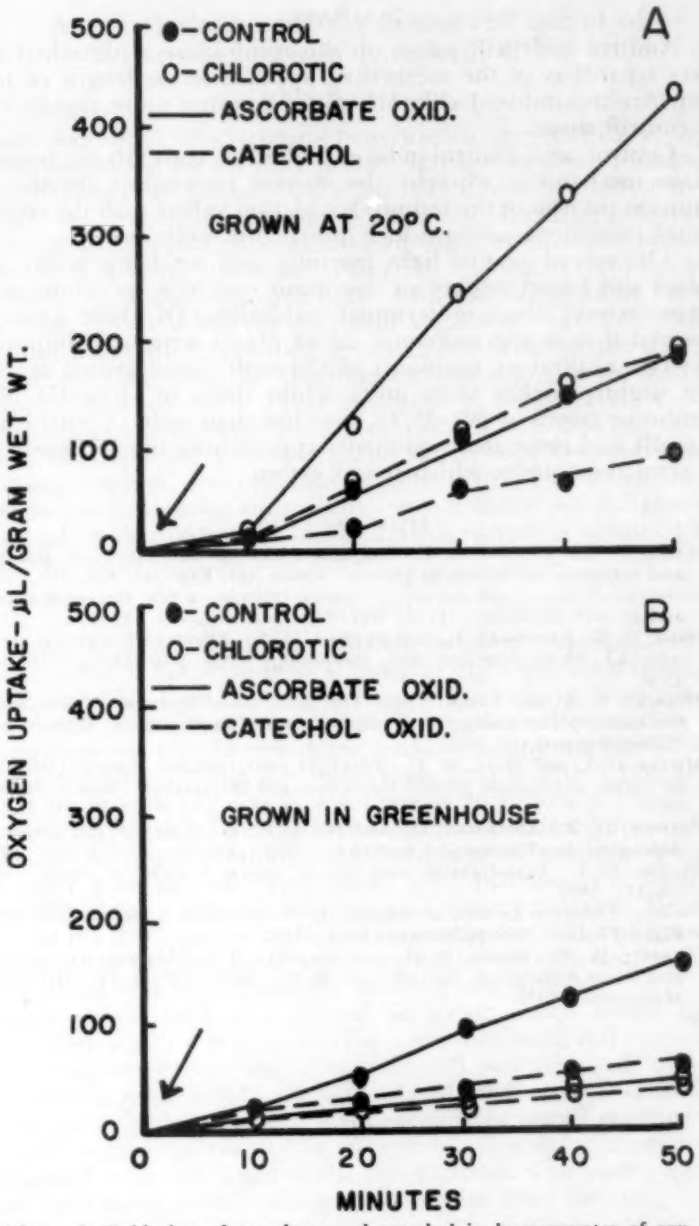



*Figure 5.* Oxidation of ascorbate and catechol in homogenates of control and chlorotic corn tissue. Arrow indicates tip-in of ascorbate and catechol. Greenhouse temperature was generally 30°–35°C.

## SUMMARY

1. Amitrol had little effect on the respiration of detached corn leaves regardless of the method of application or length of treatment. Amitrol-induced chlorotic tissue respired more rapidly than did control tissue.

2. Control and amitrol-induced chlorotic corn plants possessed certain mechanisms whereby the enzyme responsible for the predominant portion of the terminal oxidation varied with the environmental conditions under which the plants were grown.

3. The age of plants, light intensity and air temperature were studied and found to play an important role in determining which enzyme would mediate terminal oxidation. Of these factors it appeared that temperature and age of plants were most important.

4. The respiratory quotients of chlorotic tissue grown at 20°C. were slightly higher than unity while those of chlorotic plants greenhouse-grown at 30°–35°C. were less than unity. Control tissue generally had respiratory quotients approaching unity regardless of the conditions under which it was grown.


## LITERATURE CITED


1. HALL, W. C., JOHNSON, S. P., and LEINWEBER, C. L. Chemical defoliation and regrowth inhibition in cotton. Texas Agr. Exp. Sta. Bul. 759. 1953.
2. ———, ———, and ———. Amino triazole—a new abscission chemical and growth inhibitor. Texas Agr. Exp. Sta. Bul. 789. 1954.
3. HEIM, W. G., APPLEMAN, D., and PYFROM, H. T. Effects of 3-amino-1,2,4-triazole (AT) on catalase and other compounds. Am. Jour. Physiol. 186–19–23. 1956.
4. HERBERT, R. A., and LINCK, A. J. The influence of 3-amino-1,2,4-triazole on the carbohydrate balance and respiration in Canada thistle. Plant Physiol. 32(Supplement):vi. 1957.
5. MILLER, C. S., and HALL, W. C. Effects of amino triazole salts and derivatives on cotton defoliation growth inhibition and respiration. Weeds 5:218–226. 1957.
6. PYFROM, H. T., APPLEMAN, D., and HEIM, W. G. Catalase and chlorophyll depression by 3-amino-1,2,4-triazole. Plant Physiol. 32:674–676. 1957.
7. ROGERS, B. J. Translocation and fate of amino triazole in plants. Weeds 5:5–11. 1957.
8. ———. Chlorosis in corn as induced by the herbicide 3-amino-1,2,4-triazole. Plant Physiol. 32(Supplement):vi–vii. 1957.
9. UMBREIT, W. W., BURRIS, R. H., and STAUFFER, J. F. Manometric techniques and tissue metabolism, 2nd ed., pp. 30–39. Burgess Publ. Co., Minneapolis, Minnesota. 1949.

# An Explanation for the Selective Control of Barnyardgrass in Rice with CIPC

JOHN B. BAKER[1]

SINCE isopropyl *N*–(3–chlorophenyl)carbamate (CIPC) is being recommended for use on a limited acreage[2] to control barnyardgrass (*Echinochloa* species) in drilled rice, it was of interest to the author to investigate the mechanism of selectivity involved. Although a difference in sensitivity among graminaceous plants to isopropyl *N*–phenylcarbamate (IPC) (1, 6, 7) and CIPC (6) has been recorded, the author was unable to find any explanation for this difference. Observations in the field indicated that *Echinochloa* seedlings were killed regardless of the depth at which the seed was located; whereas, most rice seedlings escaped injury if the seed was planted sufficiently deep. There appeared to be, however, a difference in response among varieties of rice.[3] The following investigation was initiated to explain the differential response among varieties; however, the conclusions were expanded to explain the selective mechanism for controlling barnyardgrass in rice. The data presented in this paper are representative of results obtained in a series of experiments on this subject.

## METHODS

Flats of Lintonia silt loam soil were sub-irrigated until the soil was saturated. They were then allowed to dry until the soil became friable, at which time rice was planted. Nine varieties were planted in each flat. Three flats were planted with the seed covered by one inch of loose soil and three with the seed covered by one and one-half inches of loose soil. The flats were then treated with CIPC at the rate of six pounds per acre in a volume of 20 gallons per acre. The flats were then placed in the greenhouse and watered from above as needed to insure germination. Emergence of seedlings began 4 days after planting, and two weeks after planting, the seedlings were washed from the soil, keeping each variety separate. Measurements of the distances from the soil surface to the seed and from the soil surface to the first node were then taken on each seedling, and it was noted whether or not the seedling was injured.

Barnyardgrass seed were placed on moist paper towels in an enamel tray which was then covered with aluminum foil to exclude light. After three days the aluminum foil was removed, and the tray covered with cellophane and placed under continuous light for 24 hours. This treatment was necessary to assure germination. The seed were then planted in flats at ½, 1, and 1½ inch depths and treated with CIPC just as the rice varieties. The same measurements were made after washing the seedlings from the soil.

[1]Assistant Professor, Plant Pathology Department, Agricultural Experiment Station, Louisiana State University, Baton, Rouge, Louisiana.

[2]Smith, R. J., Jr. Private communication.

[3]Jodon, N. E., 47th Annual Progress Report, Rice Experiment Station, Crowley, Louisiana.

After the data were collected, regression coefficients were calculated for the node depth-seed depth relationship for each variety. By coding the injured plants as 1 and the uninjured plants as 2, it was possible to calculate correlation coefficients on the injury-node depth and injury-seed depth relationships.

## Results and Discussion

Figures 1, 2, and 3 are scatter diagrams showing the node depth, seed depth and injury relationships of three of the varieties. The

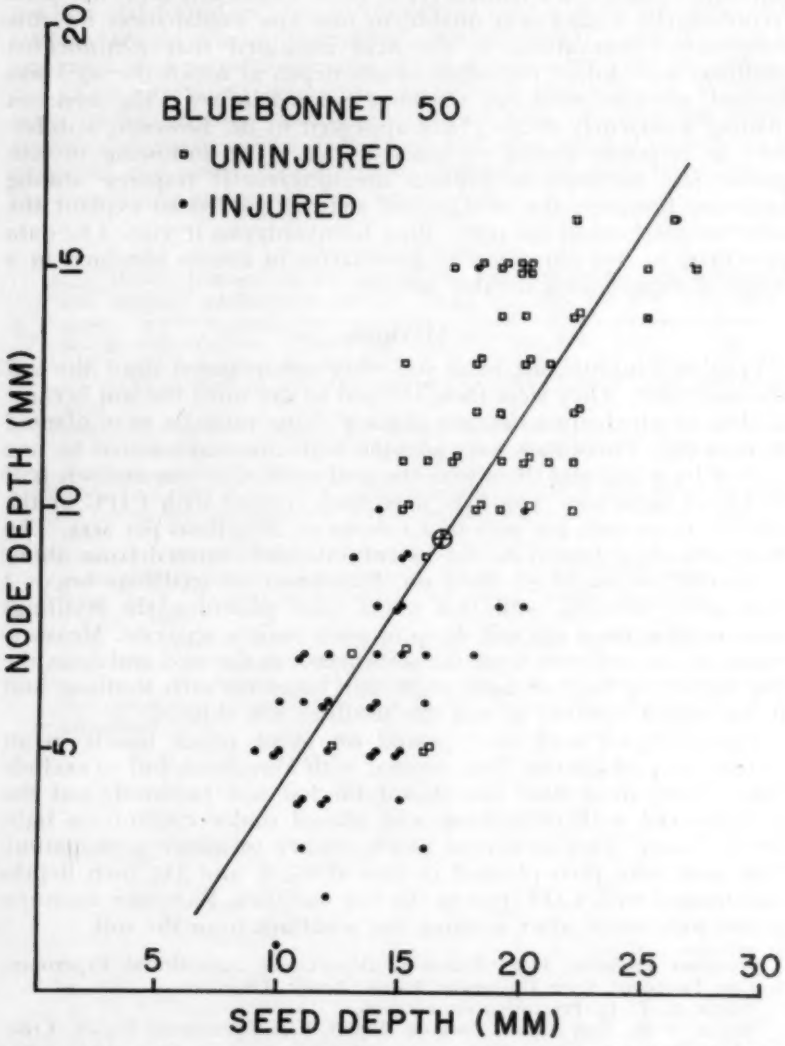



*Figure 1.* Scatter diagram of Bluebonnet 50 seedlings showing the line of regression of node depth on seed depth and the mean node depth and seed depth.

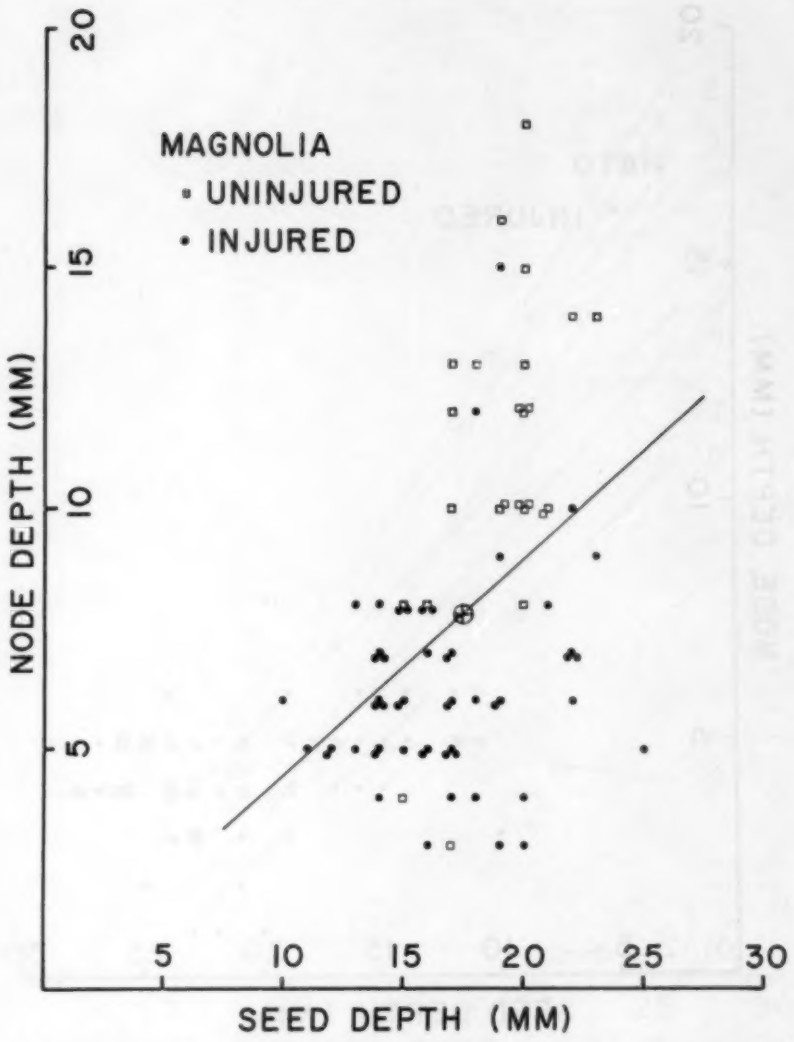



*Figure 2.* Scatter diagram of Magnolia seedlings showing the line of regression of node depth on seed depth and the mean node depth and seed depth.

mean values for seed depth and node depth and the lines of regression of node depth on seed depth for all nine rice varieties and barnyardgrass are shown in Figure 4. Table 1 gives the correlation coefficients for the injury-node depth and injury-seed depth relationships.

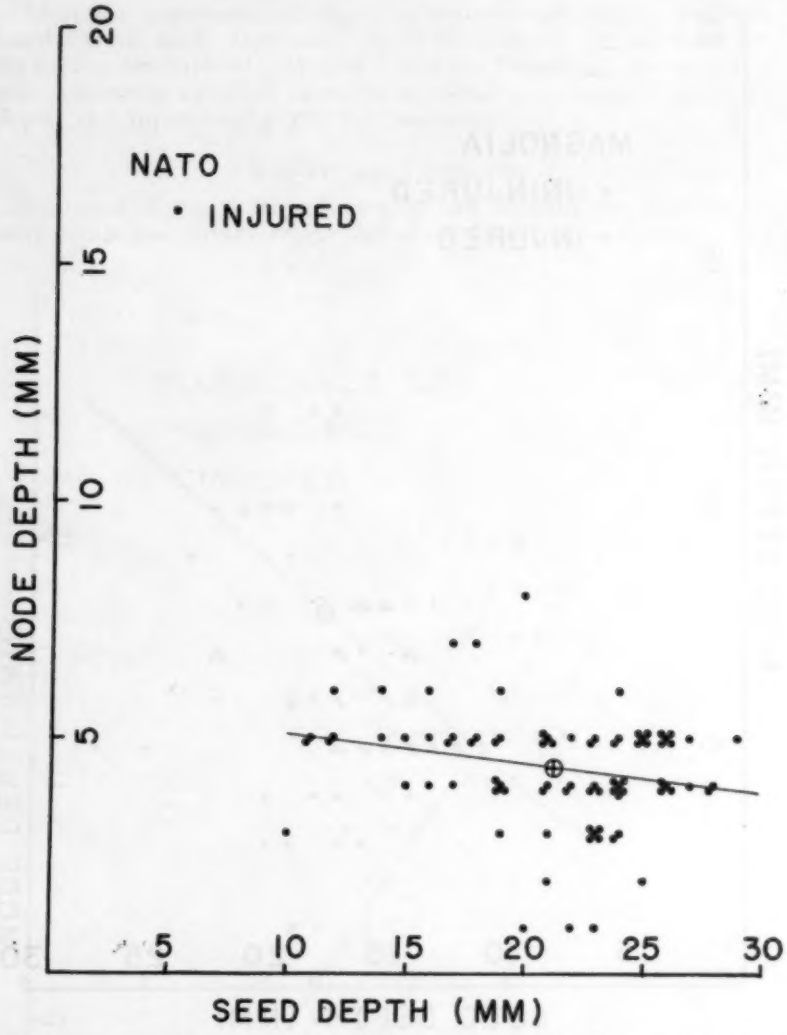



*Figure 3.* Scatter diagram of Nato seedlings showing the line of regression of node depth on seed depth and the mean node depth and seed depth.

Figure 5 shows the appearance of the rice seedlings at the time measurements were made. Note the treated Nato seedling which shows typical CIPC injury to rice. Injured seedlings are stunted, the leaves are dark green, and no adventitious roots develop at the first node which becomes dark brown.

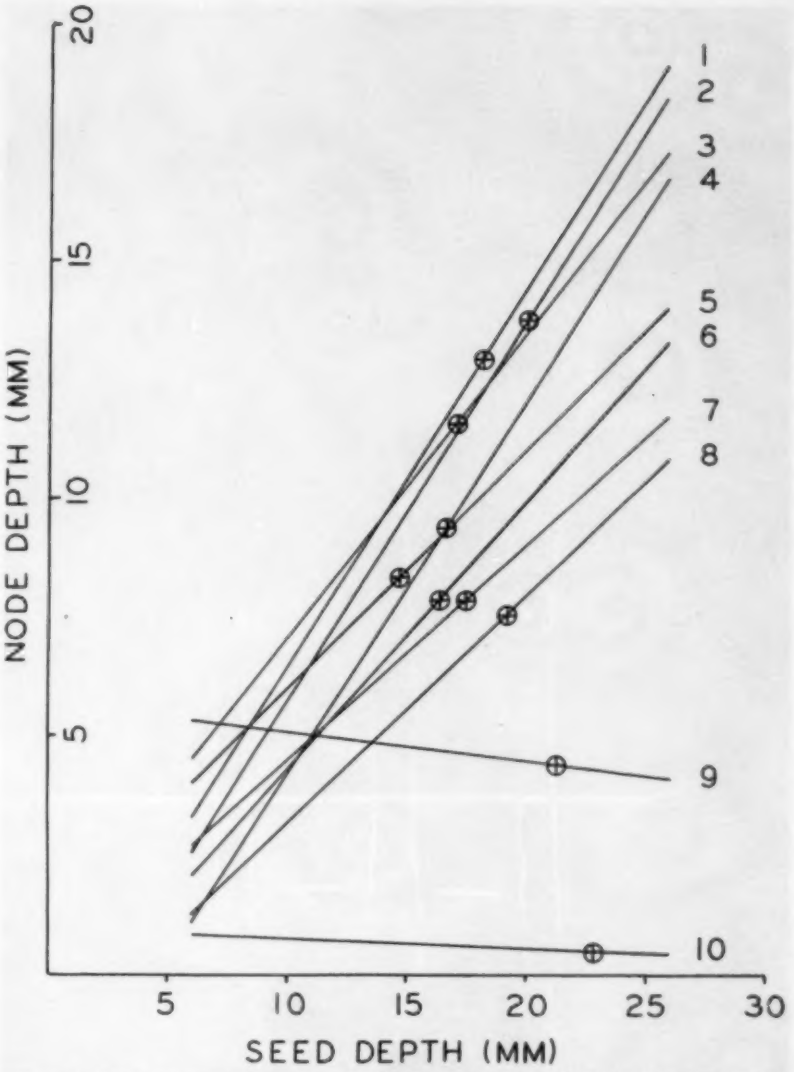



*Figure 4.* Lines of regression of node depth on seed depth and node depth and seed depth means for: (1) Sunbonnet, (2) Rexora-Red, (3) Rexora, (4) Bluebonnet 50, (5) Zenith, (6) Toro, (7) Magnolia, (8) Texas Patna 49, (9) Nato, and (10) Barnyardgrass.

Bluebonnet 50 (Figure 1) is typical of the varieties which have a high regression of node depth on seed depth. In this case there is very little difference between the injury-node depth and injury-seed depth correlation coefficients. Magnolia (Figure 2) is typical of the varieties which have a lower regression of node depth on seed depth.

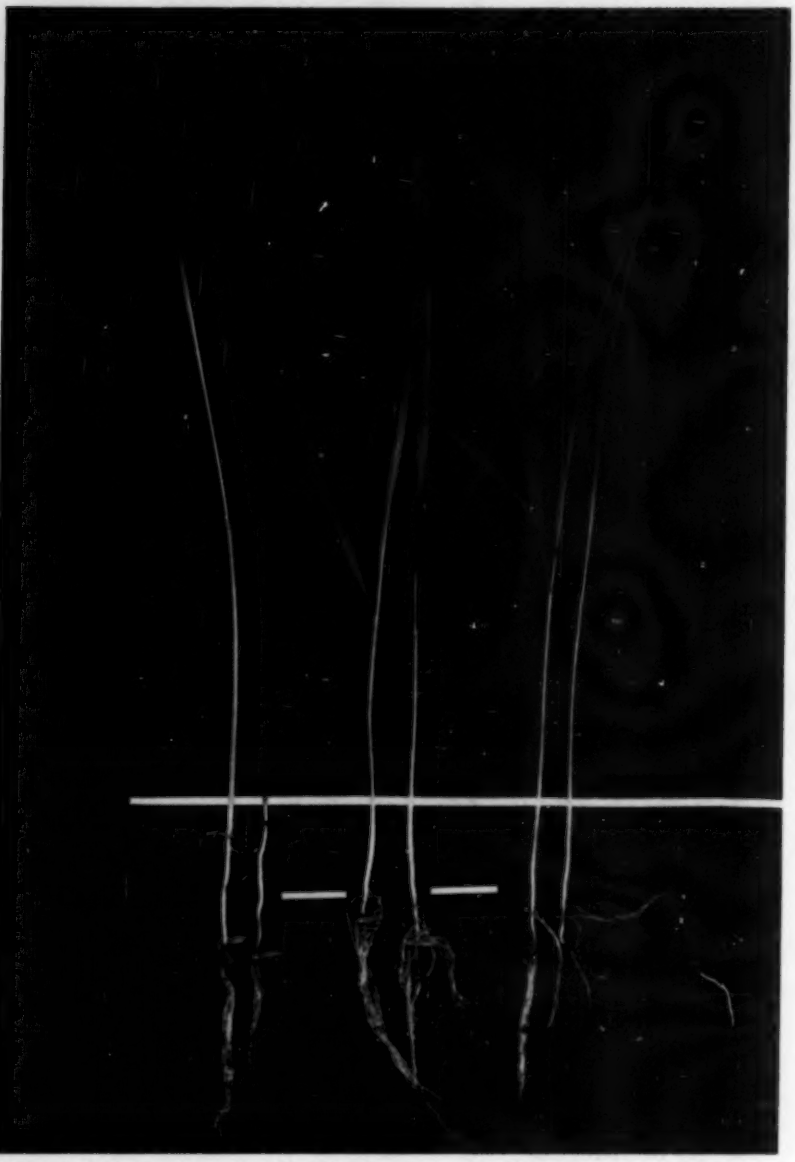


*Figure 5.* Rice seedlings at time of measurement. Left pair, Nato. Center pair, Sunbonnet. Right pair, Rexoro. Right seedling of each pair from treated flat. Top marker represents the soil surface and the lower marker represents the one inch depth.

*Table 1.* Correlation coefficients.

| Variety | Injury | Injury |
|---|---|---|
| | Node depth | Seed depth |
| Sunbonnet | .28 | .33 |
| Rexoro—Red | .67 | .59 |
| Bluebonnet 50 | .73 | .68 |
| Rexora | .45 | .27 |
| Magnolia | .65 | .35 |
| Toro | .73 | .63 |
| Zenith | .62 | .27 |
| Texas Patna 49 | .64 | .31 |
| Nato | * | * |
| Barnyardgrass | * | * |
| All varieties | .66 | .31 |

*100 per cent injury.

In these varieties the injury-node depth correlation coefficients are considerably higher than the injury-seed depth correlation coefficients. Nato variety (Figure 3) has a regression coefficient which is not significantly different from zero, but since all plants were injured no correlation coefficients for the injury-node depth or injury-seed depth relationships could be calculated.

From these data it appears that the depth of planting is correlated with injury only as long as there is a regression of node depth on seed depth. The fact that Nato variety, which has no regression of node depth on seed depth, was injured at all planting depths corroborates this point.

Barnyardgrass, like Nato variety, has no regression of node depth on seed depth but develops its first node near the soil surface regardless of seed depth. Figure 6 shows the appearance of treated and untreated barnyard grass seedlings.

It has been clearly demonstrated that root uptake is the primary means of entrance of IPC into the plant (2, 4). Ennis (5) explained the increased tolerance of older cereal plants to IPC as being due in part to the fact that the older plants may have a deeper root system. Crabtree and Loeffler (3) also reasoned that older plants show less response because of the roots being in soil below CIPC penetration.

Although no determinations were made on the movement of the CIPC in the soil in these experiments, the rice injury-node depth observations indicate that it remained near the soil surface.

In light of these data, it is suggested that the selective control of barnyardgrass in drilled rice is due to the fact that the grass seedlings produce the first node at the soil surface where the CIPC concentration is high; whereas, most varieties of rice, when planted sufficiently deep, produce the first node in soil into which CIPC has not moved and thereby escape injury.

## SUMMARY

Data are presented to show that injury to rice seedlings from preemergence treatment with CIPC is dependent upon the develop-

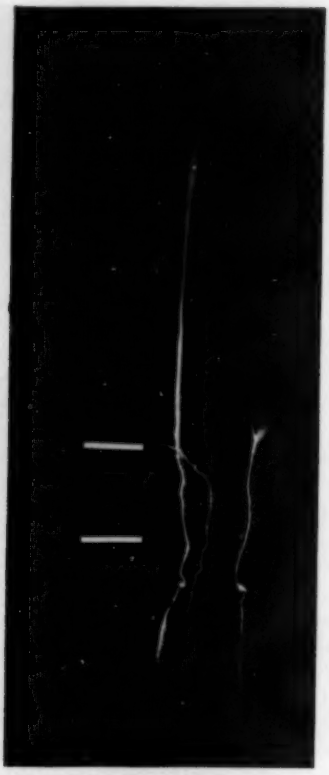


*Figure 6. Echinochloa* seedlings. Seedling on the right is from a treated flat. Top marker represents the soil surface and the lower marker represents the one inch depth.

ment of the first node near the soil surface. *Echinochloa* seedlings produce their first node at the soil surface and are killed by CIPC treatment; whereas, rice seedlings which develop the first node well below the soil surface escape injury. It is suggested that selective control by CIPC is obtained because of this difference in the morphology of the seedlings.

ACKNOWLEDGEMENT

The author would like to express his appreciation to Dr. E. C. Tims for taking the photographs which appear in the paper.

LITERATURE CITED

1. ALLARD, R. W., ENNIS, W. B., JR., DE ROSE, H. R., and WEAVER, R. J. The action of isopropyl phenyl carbamate upon plants. Bot. Gaz. 107:589–596. 1946.

2. BALDWIN, R. E., FREED, V. H., and FANG, S. C. Absorption and translocation of carbon-14 applied as O-isopropyl N-phenyl carbamate in *Avena* and *Zea*. Jour. of Ag. and Food Chem. 2:428–430. 1954.
3. CRABTREE, G, and LOEFFLER, G. Some relations of growth to plant response to isopropyl *N*-(3-chlorophenyl)carbamate. Proc. NEWCC 10:256–259. 1956.
4. ENNIS, W. B., JR. Some effects of O-isopropyl N-phenyl-carbamate upon cereals. Science 105:95–96. 1947.
5. ————. Responses of crop plants to O-isoproply-N-phenyl carbamate. Bot. Gaz. 109:473–493. 1948.
6. FREED, V. H. IPC and chloro IPC as representative carbamates as herbicides. Proc. WWCC 13:21–27. 1952.
7. MITCHELL, J. W., and MARTH, P. C. Sensitivity of grasses and some crop plants to IPC. Science 106:15–17. 1947.

# Molecular Structure and Herbicide Adsorption[1]

A. C. Leopold, P. van Schaik and Mary Neal[2]

The physical adsorption of chemical substances onto surfaces in soils or inside plants has been of considerable interest with respect to the fate of herbicides in soils, the selectivity of growth regulator herbicides, and even with respect to the toxic activities of growth regulators in plants. Comparative measurements of the adsorption of various herbicides are limited in number and scope. Experiments are presented here which attempt to measure the relative adsorptive qualities of various chlorinated phenoxyacetic acids, and to provide some evidence concerning the bearing of adsorption on herbicidal action.

## Methods

As an adsorbing medium activated carbon was selected (Atlas Powder Company) following the report by Weaver (9) that 2,4–D is strongly adsorbed on it. Since the adsorbing quality of a slurry of carbon in water changes with time, care was taken to always use a slurry which had been made up within a few minutes of the test. Unless otherwise indicated, the tests were run as follows: 5 ml of carbon slurry were added to 5 ml of the phenoxyacetic acid or other acid being tested to make a mixture of 400 mg/L carbon in $10^{-4}$M acid. The mixture was shaken on a Burrell Shaker for ten minutes, and then drawn through a steel suction filter fitted with Whatman #1 filter paper. The absorbance of the filtered solution was measured in a DU spectrophotometer at 230 mμ, which value was then taken as a measure of the acid remaining in the unadsorbed state. The results are expressed as the per cent difference between this reading and the absorbance at the same wavelength of the same solution diluted with water instead of with carbon slurry. Each value reported here is the average of at least four measurements from separate runs.

Adsorption was also measured by radioactivity on the carbon following exposure to 2,4–D tagged at the carboxyl carbon. To a 10 ml aliquot of carbon slurry was added 1 ml of radioactive 2,4–D such as to provide the final concentration of 2,4–D desired. The solution was shaken for five hours before suction filtration. The filter paper was placed directly into a counting cup, dried, and counted for radioactivity in a windowless gas flow counter. The 2,4–D at $10^{-3}$M had a total radioactivity of 2713 cpm per ml; all radioactivities are corrected for background. Each value reported is the mean of 3 to 6 replicates.

The determination of solubilities was made as follows: Saturated solutions of the acids were made by shaking an excess of crystals in

[1]Journal Paper No. 1376, Agricultural Experiment Station, Lafayette, Indiana.

[2]Professor of Horticulture, Purdue University; Research Agronomist, USDA, Brawley, California; and Assistant in Horticulture, Purdue University, respectively.

water for two days at about 25°C. Each solution was then diluted 1:10 with water and the absorbance measured on the spectrophotometer at 280 mμ. The molar concentration of this diluted solution was then determined by comparison with the absorbance curve for a known concentration series of the acid being measured. The molarity of the saturated solution was ten times that of the diluted sample.

Adsorption of other herbicides was measured in the same manner as in the case of the phenoxyacetic acids, but concentrations in the solutions were measured at the following wavelengths: 3–(*p*–chlorophenyl)–1,1–dimethylurea (monuron) at 245 mμ; isopropyl *N*–(3–chlorophenyl)carbamate (CIPC) and isopropyl *N*–phenylcarbamate (IPC) at 234 mμ; *N*–1–naphthylphthalamic acid (NPA) at 285 mμ; trichlorobenzoic acid (TCB) at 230 mμ; and trichloroacetic acid (TCA) at 205 mμ.

## RESULTS

In order to establish the quantitative nature of the adsorption processes in the test system, adsorption of 2,4–D was measured as a function of its concentration. Serial dilutions of radioactive 2,4–D were exposed to the carbon for five hours. The carbon was then filtered off and its radioactivity was measured. Data for such an experiment are given in Figure 1. The concentrations of 2,4–D and the relative amounts adsorbed (as counts per minute) are plotted on a log scale in order to establish the concentration range over which the Freundlich adsorption theory (7) would hold: that is, that the log concentration adsorbed is proportional to the log concentration applied. It can be seen that the linear function predicted by the Freundlich theory holds over a concentration range from about $2 \times 10^{-6}$ to about $10^{-4}$M.

By filtering aliquots at various time intervals after mixing 2,4–D with carbon slurry it was established that adsorption was almost complete in 90 seconds, although further small amounts were adsorbed over a five minute period. Heating the carbon to 95°C resulted in the release of 50 per cent of the adsorbed 2,4–D to the solution in about 2 minutes, and virtually complete release after 60 minutes. This heat lability is expected of a simple adsorption system not involving chemical bonding.

The influence of pH on the adsorption of 2,4–D was examined over a buffered range of 2.2 to 8.0. It was found that within this range there was a uniform adsorption.

Assuming that the ring structure of the 2,4–D molecule is the principal site of adsorption, it seemed of interest to determine the effects of chlorination of the ring on the adsorptive qualities of the molecule. One can compare various compounds on the basis of equimolar solutions presented to the carbon, or one can compare them on the basis of equal levels of saturation of the solutions presented to the carbon. The latter method would be expected to be less altered by differences in the solubilities of the compounds being compared. In order to compare the phenoxyacetic acids on the latter basis, we first established the solubilities of these chem-

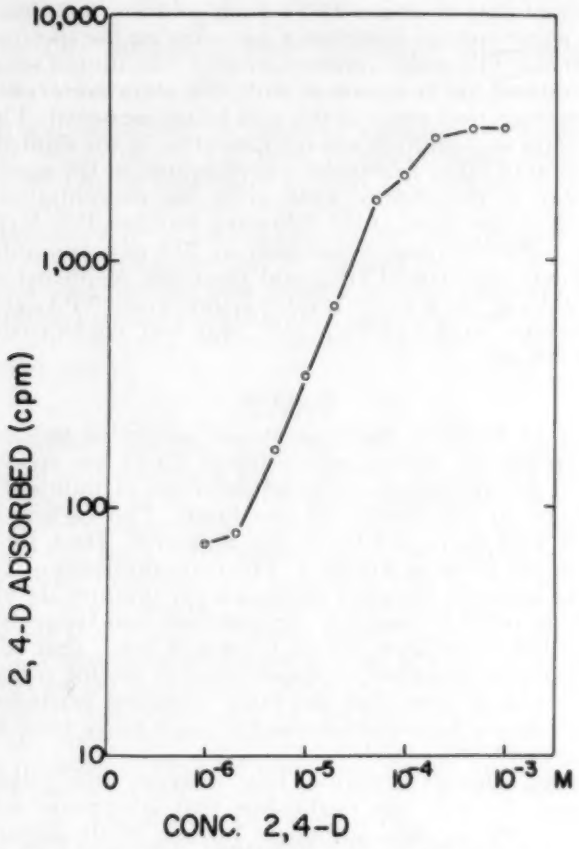



*Figure 1.* The adsorption of radioactive 2,4–D on carbon as a function of the concentration of the 2,4–D.

icals. The solubilities are presented in Table 1, from which it can be seen that the unsubstituted phenoxyacetic acid is much the most soluble member of the series, and in general, substitution of chlorine atoms onto the ring lowered the solubility, the lowest solubility being found for the 2,3,4,5,6–pentachlorophenoxyacetic acid.

By the use of optical density assays, the adsorption of the various chlorinated phenoxyacetic acids was compared by both methods—at equal molarities and at equal per cent saturations. The results of these comparisons are given in Table 2. It will be seen that the parent compound, phenoxyacetic acid, was adsorbed onto the carbon the least of all of the compounds tested, and adsorption was consecutively increased by one, two or three chlorine substitutions. Further increases in chlorination did not result in further increases in adsorption, judging from the equimolar data. The increase in adsorption with one, two or three chlorinations is evident in the

*Table 1.* The solubilities of various phenoxyacetic acids in water.

| Chlorination | Solubility (x $10^{-3}$M) |
|---|---|
| Phenoxyacetic acid | 110. |
| 2–Cl | 6.85 |
| 3–Cl | 12.65 |
| 4–Cl | 5.13 |
| 2,3–Cl | 1.55 |
| 2,4–Cl | 2.36 |
| 2,5–Cl | 2.42 |
| 2,6–Cl | 7.05 |
| 3,4–Cl | 2.07 |
| 3,5–Cl | 4.35 |
| 2,3,4–Cl | 0.80 |
| 2,3,5–Cl | 1.00 |
| 2,3,6–Cl | 2.40 |
| 2,4,5–Cl | 1.05 |
| 2,4,6–Cl | 0.97 |
| 3,4,5–Cl | 1.15 |
| 2,3,4,6–Cl | 0.39 |
| 2,3,4,5,6–Cl | 0.18 |

results of both types of tests, and the differences are somewhat greater when examined by the equal saturation type of analysis than by the equimolar type.

From the data reported in Tables 1 and 2, one would deduce that adsorption of these materials bears some relation to their solubilities. This feature is further illustrated in Figure 2, where each of the phenoxyacetic acids is plotted as a single point on the basis of its solubility and its adsorption onto carbon. It will be seen that there is a striking inverse correlation between solubility and adsorp-

*Table 2.* The adsorption of various phenoxyacetic acids onto charcoal. $10^{-4}$M or 20% saturated solutions with 400 mg/L charcoal.

| Chlorination | Per cent adsorption from | |
|---|---|---|
| | Equimolar concentrations | Equal saturation solutions |
| Phenoxyacetic acid | 8 | 6 |
| 2–Cl | 29 | 28 |
| 3–Cl | 35 | 19 |
| 4–Cl | 35 | 43 |
| 2,3–Cl | 58 | 72 |
| 2,4–Cl | 49 | 57 |
| 2,5–Cl | 48 | 60 |
| 2,6–Cl | 32 | 33 |
| 3,4–Cl | 46 | 68 |
| 3,5–Cl | 53 | 47 |
| 2,3,4–Cl | 64 | 89 |
| 2,3,5–Cl | 64 | — |
| 2,3,6–Cl | 43 | 74 |
| 2,4,5–Cl | 65 | 88 |
| 2,4,6–Cl | 51 | 83 |
| 3,4,5–Cl | 70 | 92 |
| 2,3,4,6–Cl | 59 | 95 |
| 2,3,4,5,6–Cl | 66 | 96 |

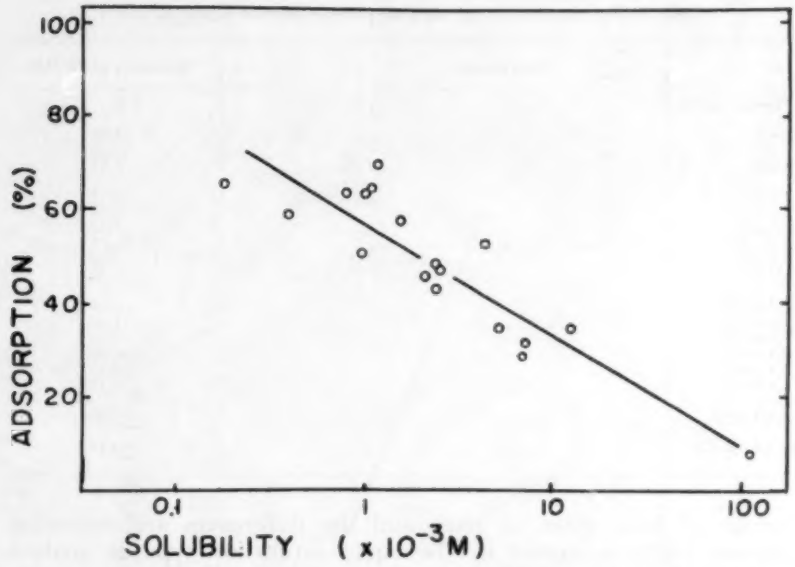



*Figure 2.* The relation of solubility of various chlorinated phenoxyacetic acids to their adsorption onto charcoal. The adsorption of each compound tested ($10^{-4}$M) is represented by one point. The correlation coefficient is −0.9901.

tion, the compounds with greatest solubility being least readily adsorbed, and those with least solubility most heavily adsorbed.

Extending this method of comparison to other herbicides, the relative adsorptions of equimolar concentrations of 7 herbicides are presented in Table 3. It is not surprising to find that the least soluble herbicides, monuron, CIPC and IPC, are the most adsorbed onto carbon; NPA, 2,4–D, 2,4,5–T, and the chlorinated benzoic acids are intermediate in this property, and TCA is very little adsorbed.

*Table 3.* The adsorption of some common herbicides onto charcoal. $10^{-4}$M solutions with 400 mg/l. charcoal.

| Herbicide | Per cent adsorption |
|---|---|
| Monuron | 98 |
| CIPC | 98 |
| IPC | 96 |
| NPA | 82 |
| 2,4,5–T | 65 |
| 2,4–D | 49 |
| TBA* | 32 |
| TCA | 13 |

*The trichlorobenzoic acid was principally the sodium salt of 2,3,6–TBA (E. I. duPont Company product).

## DISCUSSION

It has long been known that soils capture large amounts of herbicides through adsorption, but attempts to measure this function in soils have been complicated by the interference of leaching characteristics of the herbicides (4). Quantitative methods of measuring adsorption of some herbicides have been developed (3, 5, 6), but studies have not progressed far enough that one could compare members of a series and make deductions about the characteristics of herbicides that influence their adsorption.

The measurements reported here indicate that changes in the structure of the aromatic ring of phenoxyacetic acids have profound effects on their adsorption onto charcoal. Within this series, molecular changes which reduce the water solubility of the growth regulator also enhance the adsorption properties. For pre-emergence herbicides, strong adsorption characteristics are essential in order to minimize movement of the herbicide through the soil.

The adsorption values measured here are suggestive of the polarograph measurements made by Veldstra (8), from which he deduced that certain physical properties were characteristic of substances with auxin activity. It is interesting to note that the strongest auxins have intermediate adsorption values, and within the dichlorinated series, the poorest auxin (2,6–dichlorophenoxyacetic acid) has the lowest adsorption value. Within the trichlorinated series, the poorest auxins (2,3,6–trichlorophenoxyacetic acid and 2,4,6–trichlorophenoxyacetic acid) also have the lowest adsorption values.

Hellstrom (2) has noted that the toxicity curves for auxins are remarkably like the adsorption curves for such substances in the Langmuir trough. It is quite possible that the toxic reactions themselves are related to adsorption functions of these molecules inside plants. Brian and Rideal (1) have provided some evidence that selectivity of herbicides may be related to the differences in adsorption of these herbicides in different species. The property of adsorption, then, may be related not only to the mobility of pre-emergence herbicides in soils, but also to the actual toxic reactions of herbicides in the plant and the selectivity functions as well.

## SUMMARY

The adsorption onto carbon was measured for 17 of the chlorinated derivatives of phenoxyacetic acid. It was found that one, two, and three chlorine substitutions in the phenyl ring increased the adsorption properties of the molecule. A strong inverse correlation between the adsorption and solubility was found, phenoxyacetic acid being most soluble and least adsorbed of the series, and successive chlorinations decreasing solubility and increasing adsorption onto charcoal.

Grateful acknowledgement is made to Amchem Products Incorporated, Ambler, Pennsylvania, for supplying most of the chlorinated phenoxyacetic acids tested.

## LITERATURE CITED

1. BRIAN, R. C., and RIDEAL, E. K. On the action of plant growth regulators. Biochem. Biophys. Acta 9:1–18. 1952.
2. HELLSTROM, N. An attempt to explain the interaction of auxin and anti-auxin in root growth by an adsorption mechanism. Acta. Chem. Scand. 7:461–468. 1953.
3. HILL, G. D. Herbicide studies. Ph.D. Dissertation, Ohio State Univ. 1953.
4. LEOPOLD, A. C. *Auxins and Plant Growth*. Univ. Calif. Press, Berkeley. 354 pp. 1955.
5. ———. The fate of 2,4–D in plants and soils. Proc. North Central Weed Contr. Conf. 13:4. 1956.
6. OGLE, R E., and WARREN, G. F. Fate and activity of herbicides in soils. Weeds 3:257–273. 1954.
7. TRAPNELL, B. M. W. *Chemisorption*. Academic Press, New York. 1955.
8. VELDSTRA, H. Researches on plant growth substances. IV. Relation between chemical structure and physiological activity. Enzymologia 11:97–164. 1944.
9. WEAVER, R. J. Reaction of certain plant growth regulators with ion exchangers. Bot Gaz. 109:72–84. 1947.

# Achene Development of Canada Thistle and Perennial Sowthistle[1]

LYLE A. DERSCHEID and ROBERT E. SCHULTZ[2]

CANADA thistle was named *Carduus arvensis* by Tabernaemontanus in 1687, *Cirsium arvense* by Tournefort in 1700, *Serratula arvensis* by Linné in 1753, *Cirsium arvense* by Scopoli in 1772, *Carduus arvensis* by Robson in 1777 and *Cnicus arvensis* by Hoffman in 1804 (2). The name *Cirsium arvense* Tourn. was adopted (2), but more recently Canada thistle has been referred to as *Cirsium arvense* (L.) Scop. (3, 11). The cardinal number of chromosomes for the *Cirsium* genus is 17 (1).

There are at least two species of perennial sowthistle in North America. *Sonchus arvensis* L. has long glandular-hispid peduncles and involucres covered with lead-colored glandular phyllaries; whereas, the other species has glabrous involucres and peduncles (3). The second species was reported to be more common in North Dakota (9) and Western Canada (4). The smooth species has been classified as *S. arvensis,* variety *glabrescens* Guenth., Grab. and Wimm. and as *S. uliginosus* Bieb. It was established in 1955 that both classifications are correct, but for two different species (12). The species *S. arvensis* has a chromosome complement of 54, while *S. uliginosus* has only 36. Some strains containing a complement of 45 chromosomes are thought to be hybrids. The sowthistle used in this study were glabrous and were identified as *S. uliginosus* Bieb.

All flowers of an individual Canada thistle plant were found to be either staminate or carpellate (2). In the staminate head, stigmatic surfaces do not develop. In the carpellate head, there is no pollen present on the stigmatic surface when the corolla opens. This species is, therefore, dioecious and cross-pollinated.

Perennial sowthistle, on the other hand, possesses perfect flowers. Knuth is quoted (9) as having stated that the coiling of the style branches of the pistil could result in self pollination. However, in greenhouse observations where insects were almost entirely absent, flowers of *S. uliginosus* failed to set seed (9). These and other observations (7) indicate that the species is almost completely self-sterile. Isolated patches of perennial sowthistle in Iowa very seldom set seed. Self- or close-pollinated flowers from the same head or from heads in the same colony produced no seeds, while flowers cross-pollinated with pollen from a distant patch produced almost as many fruits as there were flowers in the head.

Canada thistle flowers are very fragrant and attractive to honeybees (2). The perfume of the female floret is stronger and similar

[1]Research done with funds allocated by North Central Regional Project 10, Subproject 3.

[2]Agronomist and Graduate Research Assistant deceased, respectively, South Dakota State College.

Approved for publication by the Director of the South Dakota Agricultural Experiment Station as Journal Series No. 425.

to vanilla, but the male florets are not strongly scented (5). Numerous species of insects have been observed (8) visiting Canada thistle flowers, and Knuth is quoted (9) as having observed bumble bees and hover flies visiting perennial sowthistle in Europe. Insect visitors observed in North Dakota were blister beetles and small bees (9).

The interval from the time that perennial sowthistle flowers opened until the achene was mature was about ten days (9). In heads containing some seeds, the undeveloped fruits elongate as normal ones, but in heads where all the flowers are infertile, fruits reach only half the usual length and are discolored.

The objectives of the study reported in this paper were to: (1) learn more about whether sowthistle was cross-pollinated, (2) learn more about the role of insects in pollination of both Canada thistle and perennial sowthistle, (3) determine the age of flowers of both species when the fruits became viable and (4) to determine the latest date that either species could be mowed to prevent the production of viable achenes.

The 14 experiments in this study were divided into three groups: (1) those concerned with pollination, (2) those concerned with the age of flowers when achenes became viable, and (3) those concerned with the age of flowers when mowing would prevent the production of viable seed.

## POLLINATION

The authors observed wild bees and a species of black beetle working in thistle patches at flowering time. They also observed that pistillate heads of Canada thistle, growing in a depression 200 yards across a raised highway from the nearest staminate heads, produced seed. Although seed set was light, it appeared that the pollen must have been carried by insects rather than by wind. Because of these observations, the authors decided to compare honey bees and air currents as pollinating agents.

### *Pollinating Agents*

Cuttings of Canada thistle were transplanted into a 4-foot × 20-foot greenhouse bench during the summer of 1955. Cuttings from staminate and pistillate plants were planted at a ratio of one to five. Similarly, cuttings of perennial sowthistle were transplanted into another bench.

When Canada thistle plants started flowering during the winter of 1955–56, honey bees were released in the greenhouse and 175 pistillate heads were tagged. There was an average of 1 staminate plant for each square yard of bench. The bees were removed, and the pistillate heads allowed to mature. They produced an average of 43.5 mature achenes per head. One hundred new pistillate heads were tagged, and an 18-inch fan was used to blow air across the new crop of heads for 9 hours a day for 2 weeks. There were 3 staminate heads per square yard of bench. The tagged heads were allowed to mature and they produced an average of 0.76 mature achenes per

head. The bees were returned to the greenhouse, and the plants produced seed again.

During the winter of 1956–57 this experiment was repeated on the same Canada thistle plants. One hundred pistillate heads were tagged, and there were 0.25 staminate heads per square yard while the bees were in the greenhouse. They produced an average of 45.6 mature achenes per head. Sixty-three heads were tagged, and there were 0.49 staminate heads per square yard while the fan was being used. An average of 0.21 mature achenes was developed by each head.

No fruit was produced by the perennial sowthistle plants the first year, consequently, a sowthistle experiment was conducted in the same manner during the second winter. One hundred heads were tagged before the bees were introduced, and an average of 57.7 mature achenes was produced per head. A second crop of 100 heads was tagged before the fan was put in use and an average of only 0.84 achenes per head was developed.

### *Sources of Pollen*

Since sowthistle seed production was stimulated by the use of bees as a pollinating agent, it appeared that this species might be cross-pollinated. Other observations produced similar evidence (9).

During the winter of 1956–57, 100 heads of perennial sowthistle were pollinated with their own pollen. Ninety-one failed to produce fruit, but the other 9 produced 1548 achenes. Only one seed germinated. At the same time 100 heads were pollinated with pollen from other heads on the same plant. Ninety-five failed to produce seed, but the other 5 produced a total of 637 fruits and all failed to germinate. Ten heads which were cross-pollinated with heads on different plants produced an average of 47.9 mature fruits per head, of which 80 percent were viable.

The following summer an experiment was conducted in the field in which 100 heads were selfed, 24 were closed-pollinated and 100 were cross-pollinated. Of the selfed heads, 91 failed to produce fruit, 4 produced an average of 2 achenes and 5 produced an average of 127 per head. However, none of the 637 seeds would germinate. Sixteen of the close-pollinated heads produced 1.5 achenes per head and the other 8 heads developed 887 fruits. Only 6 of the 911 achenes germinated. Of the cross-pollinated heads, 81 produced an average of 45.9 achenes of which 68 percent were viable. Five heads produced an average of less than 5 seeds and 14 did not develop achenes.

These results are in close agreement with those obtained by others (7, 9). They indicate that close- or self-pollinated flowers receiving pollen from other flowers in the same head or from other heads on the same plant do not produce many seeds, and those that do develop are not viable. The fruit appeared to be somewhat shriveled, indicating that all parts may not be present. It is possible that examination under a microscope would reveal that the embryo did not develop. However, all the seeds had been used in

germination tests before it was realized that this possibility existed.

When flowers were fertilized with pollen from other plants, they generally produced the normal number of fruits per head, and the normal number of them germinated. However, a few heads pollinated in the field did not produce seed. It is possible that poor technique was used in transferring the pollen, or that heat from the sun may have killed the pollen after it was transferred, and the paper bags replaced over the head. It is also possible that pollen was actually transferred from a different shoot of the same plant, because some transfers were made between plants growing in the same patch.

### AGE OF FLOWERS WHEN FRUITS BECOME VIABLE

In a preliminary experiment, all flowers on a patch of perennial sowthistle were removed on July 17, 1955. The next day, tags were placed on heads that opened during the intervening 24-hour period. Twenty heads were harvested on each of the fourth through the ninth days after they opened. The heads were air dried and threshed. The achenes from heads harvested on a given date were bulked. The fruits from heads 4 days old were 16 percent viable; 5 days, 7 percent; 6 days, 25 percent; 7 days, 68 percent; 8 days, 83 percent; and 9 days, 83 percent.

In a second experiment, the flowers were removed from all plants in a patch on July 16, 1956. The next day, 400–500 heads that had opened during the intervening 24-hour period were marked with white tags. A day later, 700 newly opened heads were marked with red tags. Seventy-five heads were harvested on each of the third through eleventh days after they opened. They were air dried and twenty heads for each date were threshed separately. The number of achenes was counted, and those from each head were germinated separately. A third experiment was conducted in the same manner during 1957. Twenty heads for each date were germinated in 1957, and 10 were handled in the same way after being stored for one year.

The mean number of achenes produced in each sowthistle head at various ages in 1956 and 1957 and the percentage viability of these achenes are given in Table 1.

*Table 1.* Number of perennial sowthistle achenes and their viability at various ages.

| Days after blooming | No. of achenes per head | | Per cent viable seeds | | |
|---|---|---|---|---|---|
| | 1956 | 1957 | 1956 | 1957 | 1957[a] |
| 3 | 35 | — | 0 | 0 | — |
| 6 | 79 | 21 | 0 | 10 | 8 |
| 7 | 76 | 22 | 21 | 44 | 16 |
| 8 | 61 | 27 | 77 | 59 | 59 |
| 9 | 80 | 29 | 89 | 58 | 25 |
| 10 | 65 | 40 | 81 | 77 | 34 |
| 11 | 72 | — | 84 | — | — |

[a]Germination after being held in storage one year.

*Table 2.* Number of Canada thistle achenes and their viability at various ages.

| Days after blooming | No. of achenes per head | | Per cent viable seeds | | |
|---|---|---|---|---|---|
| | 1956 | 1957 | 1956 | 1957 | 1957[a] |
| 6 | 50 | 65 | 0 | 0.1 | 0 |
| 7 | — | 80 | — | 0.6 | 0 |
| 8 | — | 75 | — | 13 | 7 |
| 9 | 53 | 80 | 1 | 80 | 28 |
| 10 | 41 | 83 | 12 | 79 | 39 |
| 11 | 47 | 75 | 85 | 85 | 49 |
| 12 | 56 | 82 | 91 | 87 | 29 |
| 13 | 42 | 80 | 85 | 77 | 36 |
| 14 | 61 | 77 | 91 | 73 | 31 |
| 15 | 63 | 76 | 82 | 77 | 20 |
| 16 | 47 | — | 90 | — | — |
| 17 | 42 | — | 90 | — | — |
| 18 | 33 | — | 88 | — | — |
| 19 | 15 | — | 78 | — | — |

[a]Germination after being held in storage one year.

Two Canada thistle experiments conducted during 1956 and 1957 were very similar to the perennial sowthistle experiments during the same years. The number of achenes per head and the percentage germination for these fruits are given in Table 2.

An average of 60 to 80 achenes developed in sowthistle heads in 1956; whereas, between 20 and 40 developed in 1957. The reason for this difference is not apparent. Different patches were used for the two experiments, but they were in the same field. It is possible that fewer insects were working in 1957, and it is also possible that early above-normal rainfall followed by rather dry weather during pollination and seed development in 1957 may have had some effect on seed set.

The reverse trend was found in Canada thistle as between 40 and 60 achenes per head developed in 1956 and between 65 and 85 developed in 1957. This difference may be due to the fact that the two patches used were in two different fields, and the second one had much better growing environment. Some shattering was observed when heads were left on the plants longer than 15 days in 1956.

Viable fruits were produced 1 or 2 days earlier in 1957 than in 1956. Ten to 20 percent germinated from heads that were harvested 6 or 7 days after they opened for sowthistle, but most of them did not germinate until a day later, which is in close agreement with other data (9) which indicated that 8 percent of 4-day old fruits would germinate and 77 percent of those 6 days old were viable. Similar results were obtained with Canada thistle. On the tenth day in 1956 and the eighth day in 1957, 12 percent of the fruits were mature enough to germinate, and over 80 percent were viable one day later during each year.

Such results indicate that flowers of perennial sowthistle must be 6 or 7 days old, and that Canada thistle flowers must be 8 or 10 days old before fruits are mature enough to germinate. The few

that germinated on these days probably were produced at the edge of the head. Those near the edge of the head open and mature earlier than those in the middle (6). Those near the middle, however, probably are not more than 24 hours younger, because a high percentage of achenes were viable a day later.

The freshly matured seeds had a higher germination percentage than those obtained in the same experiment and stored in a warm building for 1 year before being threshed. The difference was greater for Canada thistle than for sowthistle as is shown in Tables 1 and 2. There does not appear to be any correlation with age and reduced germination percentage. These results are in slight disagreement with other results (9) which indicate that sowthistle seeds germinate well after being stored for 3 years. It is probable, however, that the latter data were obtained from seeds that were threshed before being stored.

It is quite apparent that a farmer need not be concerned about thistle buds in his seed grain. In the first place, they must be open before they can pollinate, and in the second place, they must be open a week or more before the achenes are mature enough to germinate. Although there is no possibility of the buds containing viable seed, there is still a possibility when older heads are threshed that individual thistle achenes may be distributed through the grain.

### Mowing to Prevent Seed Production

During 1956, perennial sowthistle heads were tagged the day they opened, and some plants were mowed daily on the fourth through eleventh days after the heads opened. They were allowed to dry in the field for 3 days. From 5 to 15 heads from each date of mowing were threshed and germinated as in the above experiments. A similar experiment was conducted in 1957. Plants containing about 50 tagged heads were mowed on the fourth through fifteenth day after the heads opened. Twenty heads from each date were threshed and germinated.

At the same time, 2 Canada thistle experiments were conducted in the same manner. Eight to 20 heads were collected, threshed and germinated for each mowing date (fourth through seventeenth day, except for tenth day, after flowers opened) in 1956. Fifty to 100 heads were mowed on the fifth through sixteenth day in 1957, and 20 were threshed, counted and germinated separately.

Although it was known that achenes were not viable on heads that had been open less than 6 days when they were removed from the plant, it was felt that achenes on mowed plants might develop from food stored in the plant. In 2 sowthistle and 2 Canada thistle experiments, the percentage of viable seeds from heads of plants mowed at various stages of growth was very similar to the percentage of viable seeds from heads that were removed from plants at the same age. The data are given in Table 3.

When mowing of sowthistle was delayed until the eighth day after heads opened in 1956 and the sixth day in 1957, a few fruits were mature enough to germinate. However, many fruits were viable

*Table 3.* The percentage of viable achenes of Canada thistle and perennial sowthistle after being mowed at several stages of development during two years.

| Days after blooming when mowed | Per cent germination | | | |
|---|---|---|---|---|
| | Sowthistle | | Canada thistle | |
| | 1956 | 1957 | 1956 | 1957 |
| 4 | — | — | 0 | — |
| 5 | 0 | 0 | 0 | — |
| 6 | 0 | 8 | 0 | 0 |
| 7 | 0 | 8 | 0 | 1 |
| 8 | 3 | 42 | 0 | 42 |
| 9 | 86 | — | 5 | 49 |
| 10 | 83 | 38 | — | 51 |
| 11 | 75 | — | 95 | 59 |
| 12 | — | — | 57 | 59 |
| 13 | — | — | 78 | 66 |
| 14 | — | — | — | 58 |
| 15 | — | — | — | 47 |

when mowing was delayed until the ninth day in 1956 and the eighth day in 1957. Similarly, a few Canada thistle seeds were viable on heads mowed the ninth day in 1956 and the seventh day in 1957, and the majority of them were viable on plants mowed the tenth or eleventh day in 1956 and the eighth day in 1957.

Since the results are so similar to those obtained from heads that were removed from plants, there is a strong indication that very little development of thistle seed takes place on plants after they have been mowed.

## GERMINATIONS

All germination tests were conducted under conditions that had previously proved to be quick and simple. Achenes were placed on moist blotters in plastic 4-inch square germination dishes. They were given 3 days of light, 7 days of 40° F. temperature and 20 days alternating temperatures with 9 hours at 86° F. and 15 hours of 68° F. Germination readings were made twice weekly after being exposed to alternating temperatures.

## SUMMARY AND CONCLUSIONS

Fourteen experiments were conducted to study achene development of Canada thistle *(Cirsium arvense* L.) and perennial sowthistle *(Sonchus uliginosus* Bieb.). Two compared bees and wind currents as pollinating agents for Canada thistle and one made the same comparisons for perennial sowthistle; two were used to help determine whether sowthistle was self- or cross-pollinated; three studied the age of heads of sowthistle when fruit became viable and two gave similar information on Canada thistle; two were conducted on sowthistle and two on Canada thistle to determine the latest stage of growth where mowing would prevent the production of viable seed. The following conclusions can be drawn:

1. Honey bees aid in the pollination of Canada thistle and perennial sowthistle. In the greenhouse they are much more effective than air currents.

2. Perennial sowthistle is a largely cross-pollinated species. Very few achenes develop when flowers are pollinated with pollen from other flowers of the same head or from flowers on other heads growing on the same plant.
3. A high percentage of sowthistle achenes are viable about 1 week after the heads open—2 more days are required for Canada thistle. The exact number of days varies slightly from year to year.
4. Mowing must be done before heads have been open 8 or 9 days for sowthistle and 10 or 11 days for Canada thistle in order to prevent the production of viable seed. The exact number of days varies slightly from year to year.
5. The viability of seed from both species may be reduced when they are stored in the head for a year or more.

## ACKNOWLEDGMENTS

Although most of the work included in this paper was conducted by the late Robert Schultz, some of the experiments were conducted by other graduate students. Russel L. Nash conducted the 1955–56 comparison of bees and air currents as pollinating agents. Darrold Termunde conducted the preliminary test in 1955 to determine the age of sowthistle heads when viable seeds were produced. Samuel Zilke made an extensive literature review and did the field work for the 1956 studies of the age of flowers when viable seeds were produced and the mowing experiments. Robert D. Anton conducted the 1958 mowing experiments and the 1958 germination tests on seeds obtained from Schultz's 1957 experiments to determine the age of flowers when viable seeds were produced.

## LITERATURE CITED

1. AISHIMA, TOSHIYSUKI. Chromosome numbers in the genus *Cirsium* L. Botanical Magazine 48:566. 1934.
2. DETMERS, FREDA. Canada thistle, *(Cirsium arvense* Tourn.) field thistle, creeping thistle. Ohio Agr. Exp. Sta. Bul. 414. 1927.
3. FERNALD, MERRIT LYNDON. Gray's Manual of Botany, Eighth Edition. American Book Company. New York, N. Y. 1951.
4. GROH, HERBERT. Perennial sowthistle and its smooth variety in Canada. Sci. Agr. 23:127–30. 1942.
5. HAY, W. D. Canada thistle seed production and its occurrence in Montana. Seed World 41:7, 6. 1937.
6. HAYDEN, ADA. Distribution and reproduction of Canada thistle in Iowa. Amer. Jour. of Bot. 21:7, 355–73. 1934.
7. ———. Proceedings Iowa Academy of Science. 44:105. 1937.
8. RAEFFELE, ISSEL. Oasi di "Optimum" relativo insetti Hisitation dei *Cirsium* nel Territorio di Bolzano. Atti. Acad. Sci. Veneto-Trenteno-Istriano 20:93–101. 1929.
9. STEVENS, O. A. Perennial sow thistle, growth and reproduction. N. Dak. Agr. Exp. Sta, Bul. 181. 1924.
10. ———. The sow thistle. N. Dak. Agr. Exp. Sta. Cir. 32. 1926.
11. ———. Handbook of North Dakota Plants. N. Dakota Institute for Regional Studies. Knight Printing Co. Fargo, N. Dak. 1950.
12. SHUMOVICH, WILLIAM, and MONTGOMERY, F. H. The perennial sow thistles in Northeastern North America. Can. Jour. Agr. Sci. 35:601–5. 1955.

# The Chloro-substituted Benzoic Acids for Control of Field Bindweed[1]

W. M. PHILLIPS[2]

THE chloro-substituted benzoic acids discussed in this paper have been evaluated experimentally as soil sterilizing herbicides for field bindweed (*Convolvulus arvensis* L.) control at the Ft. Hays Experiment Station since 1955. The value of soil sterilization in a perennial weed control program in the Great Plains region is evidenced by recommendations made by several state experiment stations (1, 2, 3, 6, 9). Prior to 1950, most semi-permanent soil sterilization was accomplished with such chemicals as sodium chlorate, boron compounds, and arsenicals. These compounds continue to be important (8) even though the poisonous qualities of arsenic compounds and the hazards of handling sodium chlorate are well recognized.

Zimmerman and Hitchcock (10, 11) and Minarik et al. (4) reported on the physiological and growth-regulating activity of chloro-substituted benzoic acids, and Shaw and Swanson (7) suggested that they be evaluated as soil-sterilizing herbicides. Numerous workers have since issued progress reports and abstracts describing the control of perennial weeds with these compounds.[3] Phillips (5) summarized information on residual activity of the chlorinated benzoic acids in soil and reported that at Hays, Kansas, these chemicals persisted in the soil for at least three growing seasons when used at rates necessary for field bindweed control.

The purpose of the studies reported herein was to: (a) evaluate the chloro-substituted benzoic acids as herbicides for field bindweed control, (b) determine the most satisfactory time, rate, and method of application, and (c) study the residual herbicidal activity of the chemicals.

## MATERIALS AND METHODS

Duplicate square rod plots of field bindweed were treated with chloro-substituted benzoic acids on several dates and at several rates. The compound designated as 2,3,6–TBA consisted of approximately 60% 2,3,6–trichlorobenzoic acid and smaller percentages of various isomers. The polychlorobenzoic acid (PBA) consisted primarily of several isomers of dichloro-, trichloro-, and tetrachlorobenzoic acid. The third compound, designated as TBA, was made up of approximately 50% 2,3,5–trichlorobenzoic acid, 20% 2,3,6–trichlorobenzoic acid, and smaller percentages of other isomers.

All spray applications were made with a power-operated plot

[1]Cooperative investigations of the Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture and the Kansas Agricultural Experiment Station. Contribution No. 134, Ft. Hays Branch, Kansas Agricultural Experiment Station, Hays, Kansas.

[2]Research Agronomist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture.

[3]North Central Weed Control Conference and Western Weed Control Conference Research Reports for 1955, 1956, 1957, and 1958.

sprayer at 40 gallons of solution per acre. The granular compounds were spread by hand. Soil in the experimental area was classified as a Crete silty clay loam.

The original infestation of bindweed was fairly uniform over the entire experimental area and averaged approximately 400 shoots per square rod. Plants which survived treatment were counted in the fall of each year. Additional plant counts, effectiveness ratings, and general observations were made throughout the growing season. In order to make the data from the various years as comparable as possible, the plant counts reported were those taken near the end of the growing season of the year following treatment. Thus a minimum of 12 months and a maximum of 17 months elapsed between treatment and the time the data were collected.

Comparatively few applications were made in 1955 and 1956. The results obtained from these exploratory treatments served as a basis for the wider range of rates and formulations used in 1957. Numerous other soil-sterilizing chemicals were included in each experiment, but, because of its wide-spread acceptance as a soil sterilant, data from the sodium chlorate treatments were used as a standard for comparative evaluation of the benzoic acids in this report.

## RESULTS AND DISCUSSION

The sodium salt of 2,3,6–TBA was included in six of the eight experiments conducted during the period of these investigations. Sodium chlorate was used in five of these six trials.

Table 1 compares 15 or 16 lb/A 2,3,6–TBA, 30 or 32 lb/A 2,3,6–TBA, and 960 lb/A sodium chlorate with bindweed populations on untreated plots. Except for the 16 lb/A treatment in July 1957, plots treated with 2,3,6–TBA had less bindweed regrowth than those

*Table 1.* Regrowth of field bindweed in the fall of the succeeding year after treatment with sodium salt of 2,3,6–TBA or sodium chlorate, compared with untreated populations.

| Chemical | Rate lb/A[a] | Shoots per square rod following application in | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | May 1955 | Oct. 1955 | Nov. 1956 | July 1957 | Oct. 1957 | 4-date average | 5-date average |
| 2,3,6–TBA..... | 15–16 | 14 | 24 | 90 | 16 | 2 | 14.0 | 29.2 |
| | 30–32 | 10 | 2 | — | 1 | 20 | 8.2 | — |
| Sodium chlorate.. | 960 | 98 | 135 | 156 | 4 | 22 | 64.8 | 83.0 |
| No treatment..... | | 369 | 335 | 294 | 220 | 245 | 292 | 293 |

[a]15 and 30 lb/A were applied in 1955. 16 and 32 lb/A were used in subsequent tests.

treated with 960 lb/A sodium chlorate. The action of sodium chlorate may be delayed during dry weather, and moisture was deficient in 1955 and 1956 (Table 2). Therefore, the number of bindweed plants which remained on plots treated with sodium chlorate in those 2 years may be abnormally high. Likewise, because of excessive precipitation, plots treated in 1957 may not maintain the excellent control indicated. Variation in precipitation appeared to have less effect on the action of 2,3,6–TBA than on sodium chlorate.

*Table 2.* Inches of precipitation by months at Hays, Kansas, 1955 through 1958.

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1955.. | 0.45 | 0.64 | 0.15 | 3.01 | 2.48 | 3.70 | 2.09 | 0.51 | 7.63 | 0.16 | 0.09 | 0.25 | 21.16 |
| 1956.. | 0.63 | 0.60 | 0.17 | 1.28 | 1.42 | 0.38 | 2.79 | 1.07 | 0.06 | 0.74 | 0.05 | 0.02 | 9.21 |
| 1957.. | 0.19 | 0.11 | 2.44 | 2.14 | 4.08 | 6.74 | 3.11 | 3.92 | 3.49 | 1.22 | 0.80 | 0.09 | 28.33 |
| 1958.. | 0.25 | 0.99 | 3.98 | 1.62 | 6.81 | 2.33 | 7.82 | 4.35 | 1.89 | 0.54 | 0.50 | 0.13 | 31.21 |

[a]90-year average is 22.84 inches.

Except on plots treated in November 1956, treatment with 16 lb/A 2,3,6–TBA was highly satisfactory. The apparent ineffectiveness of the November 1956 application cannot be explained. However, applications of 24 lb/A 2,3,6–TBA on this date (Table 3) averaged only six bindweed shoots per square rod in the fall of 1957.

*Table 3.* Regrowth of field bindweed in the fall of the succeeding year following treatment with various rates of the sodium salt of 2,3,6–TBA and emulsifiable oil formulations of TBA and PBA.

| Date of application and rate lb/A | Shoots per square rod | | |
|---|---|---|---|
| | 2,3,6–TBA | TBA | PBA |
| July 1956 | | | |
| 15 | — | 12 | 36 |
| 30 | — | 16 | 56 |
| Average | — | 14 | 46 |
| Nov. 1956 | | | |
| 8 | 172 | 300 | 397 |
| 16 | 90 | 174 | 266 |
| 24 | 6 | 15 | 68 |
| 48 | — | 60[a] | — |
| Average | 89 | 163 | 244 |
| May 1957 | | | |
| 8 | — | 176 | 238 |
| 16 | — | 115 | 250 |
| 32 | — | 78 | 242 |
| 48 | — | 46 | 28 |
| Average | — | 104 | 190 |
| July 1957 | | | |
| 8 | — | 42[a] | 160[a] |
| 16 | 16 | 22 | 18 |
| 32 | 1 | 2 | 27 |
| 48 | — | 1[a] | 21[a] |
| Average | 8.5 | 12.0 | 22.5 |
| Oct. 1957 | | | |
| 8 | 82[a] | — | — |
| 16 | 2 | 10 | 44 |
| 24 | 1 | 8 | 13 |
| 32 | 20 | 24 | 14 |
| 40 | 3[a] | — | 14[a] |
| 48 | — | 10[a] | 43[a] |
| Average | 7.7 | 14.0 | 23.7 |

[a]Not included in the averages.

Plant counts on plots treated with 30 or 32 lb/A 2,3,6–TBA were consistently low. Differences between rates listed in Table 1 were relatively small and in the October 1957 test the 16 lb/A rate appeared more effective than the 32 lb/A rate.

*Table 4.* Regrowth of field bindweed in the fall of the succeeding year after treatment with 16 lb/A of several formulations of 2,3,6–TBA.

| Formulation | Shoots per square rod following application in | | | | |
|---|---|---|---|---|---|
| | June 1957 | July 1957 | Oct. 1957 | 2-date average | 3-date average |
| Sodium salt | 20 | 16 | 2 | 18.0 | 12.7 |
| Emulsifiable oil | 33 | 1 | — | 17.0 | — |
| Oil soluble | 22 | 62 | — | 42.0 | — |
| Lithium salt | 96 | 9 | 38 | 52.5 | 47.7 |
| Potassium salt | 40 | 8 | 7 | 24.0 | 18.3 |
| Mixed metal salt | — | — | 45 | — | — |

Table 3 compares the three chlorinated benzoic acids. Plots treated at a given rate with 2,3,6–TBA had less regrowth than those treated with comparable rates of TBA or PBA except for the 32 lb/A treatment of PBA applied in October 1957. Some discrepancies existed, but in general TBA was more effective than PBA applied at the same rate.

Six formulations of 2,3,6–TBA at 16 lb/A were compared in 1957. Table 4 gives the treatments and the number of shoots growing on the plots in the fall of 1958. The sodium salt, emulsifiable oil, and potassium salt formulations gave similar average results. On the basis of these tests, the oil-soluble and lithium salt formulations were somewhat less effective. A mixed metal salt of 2,3,6–TBA used on only one date was the least effective of the formulations tested at that time.

Throughout the experimental period differences in results following applications on the various dates were evident. There have not been sufficient data collected to assign any climatic factor or plant condition as the cause of these differences. Treatments made in July 1956 and July 1957 resulted in generally good control of bindweed. Precipitation 3 days prior to treatment in 1956 moistened the upper several inches of soil, but drought prevailed both before and after treatment. The bindweed had produced seed and was nearly dormant when the chemicals were applied. In July 1957, comparatively little bindweed topgrowth was present, but soil moisture was adequate both before and after treatment.

Following applications of 2,3,6–TBA in October 1955 bindweed control was highly satisfactory (Table 1). Likewise, treatment in October 1957 resulted in generally good control. However, considerably more bindweed regrowth occurred on plots similarly treated in November 1956 and May 1957 (Table 3). Analysis of rainfall before and after the fall treatments shows a tendency toward some correlation between rainfall prior to treatment and more complete bindweed control. This relation does not appear to exist when results from the May 1955 treatments (Table 1), which were applied during a dry period, are compared with data in Table 3 for the May 1957 test. Since different chemicals were used in the two tests, it is recognized that the data are not entirely comparable.

A comparatively small number of comparisons were made to determine the relative effectiveness of PBA applied as a spray and in dry, granular form (Table 5). Under conditions of these tests, little dif-

*Table 5.* Regrowth of field bindweed in the fall of the succeeding year after treatment with PBA applied as a spray and in granular form.

| Method of application | Rate lb/A | Shoots per square rod following application | | |
|---|---|---|---|---|
| | | July 1957 | Oct. 1957 | Average |
| Spray | 16 | 18 | 44 | 31.0 |
| | 32 | 27 | 14 | 20.5 |
| Granular | 16 | 58 | 35 | 46.5 |
| | 32 | 5 | 16 | 10.5 |

ference in bindweed control by the two materials was noticed. Observations in 1957 and 1958 indicated that spray applications of PBA during periods of warm weather usually resulted in bindweed topkill within 1 week. The granular product had little immediate effect, but topkill was nearly complete in about 30 days.

## RESIDUAL HERBICIDAL ACTIVITY

Early in the experimental program it appeared that the chlorinated benzoic acids might prevent crop production on treated soil for only a relatively short time. Continued experimentation indicates however, that benzoic acid residues toxic to many plants are rather persistent. Phillips (5) described distribution of the toxic residue on plots previously treated with 2,3,6–TBA and PBA at various rates.

When little effective rainfall was received, the treated plots remained nearly free of all vegetation. This condition is illustrated in Figure 1. During periods of higher precipitation, weedy grasses

*Figure 1.* Appearance in October 1956 of a plot treated May 1955 with 15 lb/A of 2,3,6–TBA. Drought prevailed throughout the period.

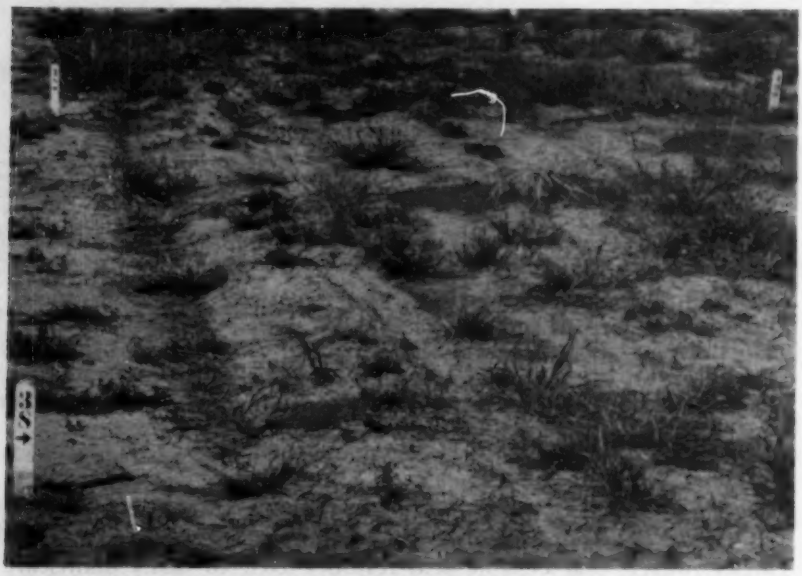


*Figure 2.* Appearance in September 1957 of a plot treated November 1956 with 24 lb/A of 2,3,6–TBA. Above-average rainfall prevailed during the second half of the period.

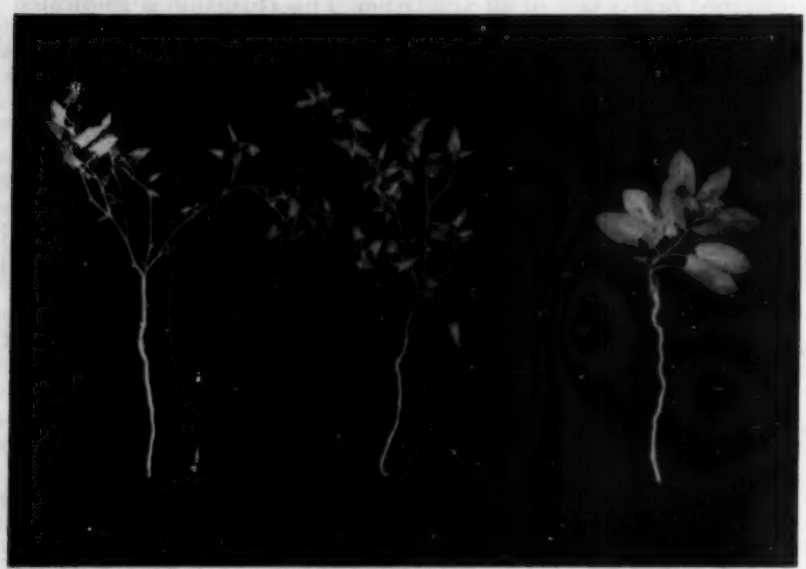


*Figure 3.* Appearance in November 1958 of bindweed plants from a plot treated May 1955 with 15 lb/A of 2,3,6–TBA (left), and a normal plant (right) from a recently cultivated area.

such as tumblegrass (*Schedonnardus paniculatus*) and crab grass (*Digitaria* spp) and other shallow-rooted plants began growing on the plots a few months after treatment (Figure 2).

Other weeds, such as fireweed (*Kochia scoparia*), exhibited symptoms of growth-regulator effect for as long as 3 years after treatment. Figure 3, taken in November 1958, compares a normal bindweed plant and plants which were growing on a plot treated with 15 lb/A of the sodium salt of 2,3,6–TBA in May 1955. This appears to give conclusive evidence that the chemical, or phytotoxic products of its breakdown, remain in the soil for extended periods.

Research is continuing to determine more fully the effect of phytotoxic residues on crop yields. However, results to date indicate that production of winter wheat and sorghum will be reduced for at least 2 years following treatment with chlorinated benzoic acids at rates necessary for bindweed control. Soil type and amount and distribution of precipitation undoubtedly influence the rate of disappearance of the residues.

## SUMMARY AND CONCLUSIONS

Three chloro-substituted benzoic acid compounds were applied to field bindweed at several rates on several dates in 1955, 1956, and 1957. All materials contained mixtures of variously substituted acids and isomers, but they were designated as 2,3,6–trichlorobenzoic acid (2,3,6–TBA), trichlorobenzoic acid (TBA), or polychlorobenzoic acid (PBA).

According to plant counts made 12 to 17 months after treatment, 2,3,6–TBA at 15 or more pounds per acre was equal or superior to 960 lb/A sodium chlorate for controlling field bindweed and less dependent on rainfall. It appeared that 15 to 20 lb/A of 2,3,6–TBA were adequate in a practical control program.

At a given rate of application 2,3,6–TBA was most effective, TBA next and PBA least effective. It appeared that PBA should be applied at about twice the rate of 2,3,6–TBA.

Sodium salt, potassium salt, and emulsifiable-oil formulations of 2,3,6–TBA gave similar results. In a few comparisons, a granular formulation of PBA was as effective as when it was applied as a spray.

Some shallow-rooted vegetation may grow on treated areas a few months after applying the chemical, but residues sufficient to reduce wheat and sorghum growth have persisted for 2 or more years.

## LITERATURE CITED

1. BAKER, L. O., HODGSON, J. M., KRALL, J. R., BRANSON, F. A., BARNARD, E. E., and HEIKES, P. E. Weed control in Montana. Mont. Agric. Expt. Sta. Cir. 210. June 1956.
2. CHAFFIN, WESLEY. Bindweed control in Oklahoma. Okla. State Univ. Extension Cir. E-668. July 1958.
3. DERSCHEID, LYLE A., and WILSON, LLOYD R. Weed control in South Dakota. S. Dak. Agric. Expt. Sta. Cir. 102. March 1954.
4. MINARIK, C. E., READY, D., NORMAN, A. G., THOMPSON, H. E., and OWINGS, J. FRED, Jr. New growth regulating compounds. II. Substituted benzoic acids. Bot. Gaz. 113:135–142. 1951.

5. PHILLIPS, W. M. Residual herbicidal activity of some chloro-substituted benzoic acids in soil. Weeds 7:284–294. 1959.
6. ———, and TIMMONS, F. L. Bindweed—how to control it. Kans. Agric. Expt. Sta Bul. 366. August 1954.
7. SHAW, W. C., and SWANSON, C. R. An evaluation of several chemicals for their herbicidal properties. 1954 field results. USDA Progress Report. Processed publication March 1955.
8. UBEL, JAKE R. Regulatory work in Kansas. Weeds 6:468–471. 1958.
9. WIESE, A. F., and REA, H. E. Bindweed control in the Panhandle of Texas. Texas Agric. Expt. Sta. Bul. 802. April 1955.
10. ZIMMERMAN, P. W., and HITCHCOCK, A. E. Growth-regulating effects of chloro-substituted derivatives of benzoic acid. Cont. Boyce Thompson Inst. 16:209–213. 1951.
11. ———, and ———. Substituted phenoxy and benzoic acid growth substances and the relation of structure to physiological activity. Cont. Boyce Thompson Inst. 12:321–344. 1942.

# Response of Pensacola Bahiagrass to Herbicides[1]

C. C. Black and E. G. Rodgers[2]

Pensacola bahiagrass (*Paspalum notatum* F.) is a leading pasture grass in the Southeastern and Gulf Coast states where it produces high quality forage on relatively infertile soils low in available moisture. It is a major seed crop on which many farmers rely as a cash crop. Weeds compete strongly with this grass during its establishment and even after establishment of a sod, various annual or perennial weed species may encroach. Control of such weeds often is desirable.

Grasses vary in their tolerance of herbicides, but the most common grasses are sufficiently tolerant to allow the use of certain herbicides. The phenoxy herbicides are almost universally used on grasses. Several workers (1, 2, 3) reported that 2,3,6–trichlorobenzoic acid (2,3,6–TBA) at rates from 1 to 4 lb/A was applied without injury to various grasses.

Nutter (5) reported that 5 lb/A of maleic hydrazide (MH) injured common bahiagrass more than Pensacola bahiagrass, but the injury was not serious for either grass. McCaleb[3] stated that 3–amino–1,2,4–triazole (amitrol) at rates as high as 15 lb/A did not seriously damage Pensacola bahiagrass.

Although considerable research data illustrate the degree of herbicidal tolerance of many grass species, relatively little effort has been directed toward determination of this tolerance for Pensacola bahiagrass. The primary purpose of this series of experiments, therefore, was to evaluate the response of Pensacola bahiagrass at various growth stages to several herbicidal treatments.

## Materials and Methods

This study was initiated in October, 1955, near Gainesville, Florida, and consisted of five individual experiments. Diesel oil was used as the solvent for 2,3,6–TBA and water was used for other herbicides in all experiments, except as noted.

*Experiment 1.*

Thirty duplicated herbicidal treatments in a randomized block design were applied to Pensacola bahiagrass seedlings in flats under greenhouse conditions. Each flat, 24 x 16 x 3 inches and containing Lakeland fine sand, was separated into four quarter-sections. The first section was planted with grass seed October 28, 1955, and the

[1]Fla. Agric. Exp. Sta. Journal Series, No. 888. This paper is adapted primarily from an M.S. thesis presented by the senior author to the Graduate School, University of Florida, 1957. This research was supported in whole or in part by the United States Air Force under Contract AF 08 (616)-38, monitored by the Air Force Armament Center, Eglin Air Force Base, Florida.

[2]Graduate Fellow, College of Agriculture, and Professor of Agronomy and Agronomist, Florida Agricultural Experiment Station, respectively, University of Florida, Gainesville, Florida.

[3]McCaleb, J. E. Private Communication.

remaining three sections were planted at successive 2-week intervals to provide the following four plant growth stages March 16, 1956, when the treatments were applied:

1. Two inches and under in height, three to five leaves, no tillers.
2. Two to five inches in height, only one tiller.
3. Three to five inches in height, more than one tiller.
4. Over five inches in height, three or more tillers.

Herbicides used in this experiment were a 1:1 mixture of propylene glycol butyl ether esters of 2,4–dichlorophenoxyacetic acid (2,4–D) and 2,4,5–trichlorophenoxyacetic acid (2,4,5–T), propylene glycol butyl ether ester of 2,4,5–T, and triethanolamine salt of 2,4,5–T at 1½, 3, 6, and 9 lb/A acid equivalent; also propylene glycol butyl ether ester of 2–(2,4,5–trichlorophenoxy)propionic acid (silvex), iso-octyl ester of silvex, propylene glycol butyl ether ester of 2,4–D, amitrol, an oil-soluble formulation of 2,3,6–TBA, and an emulsifiable formulation of 2,3,5,6–tetrachlorobenzoic acid (2,3,5,6–TBA) at 1½, 3, and 6 lb/A active ingredient were included. Thirty-six gallons of spray solution per acre were used.

Plant responses were observed regularly for 10 weeks after treatment.

*Experiment 2.*

All herbicides used in Experiment 1 were applied at 1½, 3, 6, and 9 lb/A active ingredient on July 20, 1956, to a 4-year-old sod of Pensacola bahiagrass during rapid summer growth of the grass. A split plot design with four replications was used with herbicides as main plots and rates as sub-plots. Sub-plots were 10 x 20 feet in size. Twenty-eight gallons of solution per acre were used.

Three weeks after treatment, an area 2.5 x 20 feet in each sub-plot was mowed and raked clean. Two and 4 weeks later the same area in each sub-plot was mowed and raked. The dry weight of grass clippings was determined for each mowing. Plant responses to treatments were observed periodically throughout the remainder of the 1956 growing season and again in the spring of 1957.

*Experiment 3.*

Pensacola bahiagrass was seeded with a cultipacker June 4, 1956, at 10 lb/A on newly cleared Kanapaha fine sand. A split plot design with four replications was used in which main plots were herbicides, sub-plots were rates of application, and sub-sub-plots 6 x 10 feet in size were dates of application. The same herbicidal treatments used in Experiment 2 were applied first July 25, when seedlings had two to five leaves fully developed. The second and third applications were made to respective sub-sub-plots at successive two-week intervals when plants had developed four to six and five to eight leaves, respectively. This allowed evaluation of the response of bahiagrass seedlings at three different growth stages to the respective herbicidal treatments. The herbicides were applied in approximately 20 gallons of solution per acre. Visible seedling responses to treatments were observed and recorded periodically through October.

*Experiment 4.*

This experiment was conducted on Lakeland coarse sand in an

abandoned field, in the same manner and at the same time as Experiment 3. Numerous native weeds were present prior to seedbed preparation. The area was cultipacked after planting at right angles to the direction of planting. In September, sample counts of Pensacola bahiagrass, other grasses, and broad-leaved weeds were made in each sub-sub-plot.

*Experiment 5.*

One-fourth of each of 84 greenhouse flats containing sterilized Lakeland fine sand soil was seeded with Pensacola bahiagrass June 19, 1956. The three remaining quarter-sections of each flat were seeded at subsequent intervals of two weeks.

Herbicidal treatments replicated twice in a randomized block design were applied September 30, in 36.6 gallons of solution per acre on seedlings varying from three to six inches high and from one to several stems per plant. Since this experiment was intended primarily to determine effects of herbicidal solvents, a 1:1 mixture of propylene glycol butyl ether esters of 2,4–D and 2,4,5–T was applied in water, diesel oil, and a 10:1 water:diesel oil emulsion. Additional treatments applied in water and the 10:1 water-oil emulsion were propylene glycol butyl ether ester of 2,4,5–T, triethanolamine salt of 2,4,5–T, propylene glycol butyl ether ester and iso-octyl ester of silvex, and propylene glycol butyl ether ester of 2,4–D. All materials were applied at 1½, 3 and 6 lb/A active ingredient. Specific effects of oil and water as carriers together with herbicidal effects were noted carefully for two months after treatment.

## RESULTS

*Experiment 1.*

The quickest response of the Pensacola bahiagrass seedlings growing in greenhouse flats was to oil-soluble 2,3,6–TBA, which killed the seedlings within 2 days. An aqueous solution of 2,3,5,6–TBA, however, killed only those seeedlings which were under 3 inches high when treated. Larger seedlings were damaged, but those over 5 inches high and with several stems developed at time of treatment exhibited definite signs of recovery 10 weeks after treatment. Smaller seedlings that survived had shown but little indication of recovery after ten weeks.

Visual damage to seedlings by phenoxy materials 1 week after treatment was the burning of the foliage, with the lower leaves and the tips of the remaining leaves brown in color. The unburned portions of the leaves on seedlings treated with 1½ and 3 lb/A appeared normal. Higher rates produced a pale green or yellow color. Six weeks after treatment the outer or older leaves were dead in all treatments. The inner leaves were pale with dead tips. All of the phenoxy materials, except propylene glycol butyl ether ester of 2,4,5–T, caused the development of a purplish color on the leaves. The intensity of this coloration did not seem to be correlated with the rate of herbicides applied.

Plants treated with 1½ lb/A of amitrol appeared normal 1 week after treatment, except a few blade tips were brown. Six weeks after

treatment the veins were light green with other leaf parts white. The plants were stunted and the white color was evident 10 weeks after treatment. Higher rates of amitrol produced more severe chlorosis which was evident 1 week after treatment and was still in evidence 10 weeks after treatment.

Seedlings at all growth stages were damaged to various degrees by all treatments. The smallest seedlings, under 2 inches high, were severely damaged by all treatments and were dead 6 weeks after spraying. Seedlings over 5 inches high, with several stems developed when treated, were the only ones with definite signs of recovery 10 weeks after treatment. Some other seedlings were alive but severely stunted.

*Experiment 2.*

The visual response of established bahiagrass to the mixture of the propylene glycol butyl ether esters of 2,4–D and 2,4,5–T was a slight burning of the foliage tips which lasted for about 3 weeks after treatment. Oil-soluble 2,3,6–TBA also burned the foliage tips, and little difference was evident among different rates. Six and 9 lb/A of amitrol produced some leaf chlorosis that was evident for 6 weeks after treatment, but these plants appeared normal after 8 weeks. Other treatments did not cause adverse plant symptoms at any time.

Oven dry weights of grass from the two clippings were analyzed statistically. The treatments did not reduce forage production. The only significance was a slight increase in forage production in plots treated with the 2,4–D—2,4,5–T mixture at 1½ lb/A. Higher rates did not increase or decrease forage yields.

These observations agreed in general with others that an established bahiagrass sod was tolerant to the herbicides applied.

*Experiments 3 and 4.*

Experiment 3 was conducted on newly cleared land where Pensacola bahiagrass had practically no competition from other plants. Experiment 4 was carried out in an old field in which the grass had severe competition from several annual weed species but predominantly Florida pusley *(Richardia scabra* St. Hil.). A good stand of grass was obtained in both experiments, but the stand in the old field was much denser where the tires of the tractor had run while pulling the cultipacker. This improved stand was evident soon after the seedlings appeared and still could be seen 26 months later. It was attributed to higher seed germination stimulated by a higher availability of moisture in the soil that was thoroughly packed by the weight of the tractor. Seedling evaluations were made on the denser plant stands.

The higher rates of all herbicides except 2,3,5,6–TBA and triethanolamine salt of 2,4,5–T caused more severe injury to the seedlings than lower rates. These two materials did not seriously damage the seedlings at any rate, The oil-soluble 2,3,6–TBA, particularly at 6 or 9 lb/A applied at the youngest stage of seedling growth, killed a large percentage of the plants. This effect probably was caused by the diesel oil carrier since the oil alone is highly phytotoxic. This material did not kill all seedlings in these field experi-

ments as it did in the earlier greenhouse study. The field-grown plants appeared to be more vigorous and more difficult to kill. The seedlings appeared equally tolerant to the propylene glycol butyl ether esters of 2,4,5–T and silvex, and to amitrol. The higher rates of these materials resulted only in temporary burning of the foliage; the plants appeared to be normal within four to six weeks after treatment.

Seedlings under 5 inches high and having less than three developed stems were injured by the 2,4–D—2,4,5–T mixture, propylene glycol butyl ether ester of 2,4–D, and the iso-octyl ester of silvex at rates above 1½ lb/A. Resistance to injury by all herbicidal treatments increased with the development of tillers and appeared to approach its maximum when three tillers were well developed. These results illustrated the increased herbicidal tolerance of bahiagrass seedlings with increased growth.

The presence of other grasses was variable 3 months after planting the bahiagrass. No differences in the population or density of other grass seedlings were evident among the herbicidal treatments. However, some variation occurred among the three dates of application. All rates of all herbicides, except the oil-soluble 2,3,6–TBA, generally resulted in the lowest population of other grasses when applied at the third spray date when plants were at the more advanced growth state, and a lower population at the second date than at the first. The 2,3,6–TBA showed a reverse effect—the population of other grasses was lowest after the first date of spraying and was lower following the second than the third date, most probably owing to the phytotoxicity of the diesel oil carrier.

The population of broad-leaved plants, consisting largely of Florida pusley, was decreased as the rate of herbicidal application was increased. The lowest rate, 1½ lb/A, of each herbicide was most effective in controlling the broad-leaved plants when application was made at the first spray date, and was less effective at the two later dates. For any given herbicide the degree of control provided by 3, and particularly by 6 or 9 lb/A, was not as greatly different among the three treatment dates as for 1½ lb/A. Six and 9 lb/A of the 2,4–D—2,4,5–T mixture, the propylene glycol butyl ether esters of 2,4,5–T and 2,4–D individually, 2,3,6–TBA, and amitrol killed a high percentage of all broad-leaved plants and, therefore, little to no difference occurred among the three dates of treatment.

All differences attributed to the effects of treatments were much less evident in 1957 than soon after application of the materials in 1956. During the summer of 1958 bahiagrass appeared to be established uniformly in all plots with no differences due to treatments being evident.

*Experiment 5.*

Marked injury was evident one week after treatment of bahiagrass seedlings at four growth stages in greenhouse flats. All rates of the mixture of propylene glycol butyl ether esters of 2,4–D and 2,4,5–T applied in diesel oil had killed all seedlings that were treated except a few of the oldest plants which had three or more stems developed

prior to treatment. All these seedlings were dead after the second week.

Herbicides applied in a 10:1 water:oil emulsion burned the foliage of the seedlings more severely than those applied in a water diluent. The propylene glycol butyl ether esters of silvex and 2,4–D, and the 2,4–D—2,4,5–T mixture at 1½ lb/A in the water:oil carrier killed some of the seedlings which had produced only three leaves at time of treatment, while practically no plants were killed by these treatments applied in water only. Increasing the rate of application of all herbicides to 6 lb/A caused more severe plant damage, particularly the younger plants and when treated with materials in the water:oil diluent. The diesel oil component of the diluent approximately doubled the injury to seedlings as compared to the water diluent; however, seedling injury was much less severe than when the diluent consisted entirely of diesel oil.

These findings illustrated the toxicity of this diesel oil to Pensacola bahiagrass seeedlings, particularly the younger plants. These findings also support the earlier observation that tolerance of these seedlings increased with plant size, particularly with development of three or more stems.

## DISCUSSION

Greenhouse results, substantiated by field results, suggested that stage of growth was a critical factor in determining herbicidal tolerance of the seedlings and that tolerance increased with plant size.

These results agree with many findings such as those of Klingman (4) that plants tend to be killed more easily by herbicides in the early seedling stage of growth than at later periods. However, the population of other grasses two months after treatment tended to be higher in field plots that were treated with herbicides at the earlier dates in this series of experiments. This development was associated with the severe competition offered the grass seedlings by Florida pusley. The earlier sprays were more effective than later sprays in killing this broad-leaved plant, thus eliminating or greatly reducing the competition with the developing grass seedlings. With removal of this competition, and the grass seedlings being more tolerant than the pusley to the treatments, especially at the lower rates, the grass seedlings were able to become established and flourish. When the applications were delayed even two weeks and particularly four, the other grass seedlings had been damaged and many had died because of the aggressive competition of the Florida pusley. The fact that 2,3,6–TBA applications resulted in a lower number of other grass plants in the plots treated earliest probably was related to the fact that this material, together with its diesel oil carrier, showed as much toxicity to grass as to broad-leaved plants.

Established sod of Pensacola bahiagrass was not damaged by the herbicides applied. These findings illustrate the relatively high level of herbicidal tolerance of this grass in an advanced stage of growth.

A definite relationship existed between growth stage of Pensacola

bahiagrass and herbicidal tolerance. Shortly after emergence, the seedlings were easily killed or severely damaged by herbicidal applications. Seedlings acquired more tolerance with age and an established sod of this grass tolerated dosages of many herbicides considerably in excess of that normally required for weed control. The hypothesis is advanced, therefore, that the herbicidal tolerance of bahiagrass increases with the addition of tillers and that seedlings with a minimum of three tillers will tolerate normal herbicidal applications for weed control in pastures. With added tillering the corresponding increase in fiber content of the plant and decrease in percentage of the total plant system involved in meristematic activity may be related to the higher level of herbicidal tolerance.

## SUMMARY

1. Five experiments were carried out to study the tolerance of Pensacola bahiagrass, at various growth stages from early seedlings to established sod, to each of nine herbicides applied at four rates.
2. Herbicidal tolerance of small bahiagrass seedlings was very low, but this tolerance increased as the plant grew and reached its approximate maximum level when the plants had developed a minimum of three tillers.
3. Oil soluble 2,3,6–TBA at rates of 1½ to 9 pounds active ingredient per acre in a diesel oil carrier killed all bahiagrass seedlings under greenhouse conditions. The same treatments, applied to seedlings in the field, killed a high percentage but not all of the plants. A carrier consisting partially or entirely of diesel oil for other herbicidal treatments caused more severe damage to seedlings than a water carrier for comparable treatments.
4. Seedlings which had begun tillering tolerated without material damage propylene glycol butyl ether ester of 2,4,5–T, triethanolamine salt of 2,4,5–T, propylene glycol butyl ether ester and iso-octyl ester of silvex, amitrol, and 2,3,5,6–TBA at rates up to 6 pounds per acre, and propylene glycol butyl ether esters of 2,4–D and 2,4,5–T in mixture and each alone at rates up to 3 pounds per acre.

## LITERATURE CITED

1. BALGLEY, E. HC-1281, or 2,3,6–Trichlorobenzoic acid. Proc. Calif. Weed Conf. 8:71–72. 1956.
2. HOGARD, T. W., and HEMPHILL, D. D. White clover control in bluegrass turf. Res. Report NCWCC 13:128. 1956.
3. ————, and ————. Spring control of checkweed in lawns. Res. Report NCWCC 13:129. 1956.
4. KLINGMAN, DAYTON, L. Effects of herbicides on seedling and established grasses. Proc. NCWCC 6:72–73. 1949.
5. NUTTER, G. C., and WITHERSPOON, A. Influence and effectiveness of growth retardants. Abstracts, WSA 1:48–49. 1956.

# The Use of Dalapon and Substituted Urea Herbicides for Control of Seed-bearing *Spartina* (Cord Grass) in Inter-tidal Zones of Estuarine Marsh

D. S. RANWELL[1] and B. M. DOWNING[1]

## INTRODUCTION

THE remarkable spread of a seed-bearing *Spartina* species (formerly incorrectly known as *S. townsendii* H. & J. Groves, now awaiting a new name) in mudflat areas on European coasts in the past 70 years is widely known. It was suspected from the sudden appearance of a new *Spartina* species in Southampton Water during the latter part of the 19th Century amongst accidentally introduced *Spartina alterniflora* Lois, and the British native *Spartina maritima* (Curt.) Fernald, that the plant was of hybrid origin. Some of the plants were found to be polyploid and this suggested an explanation for the extreme vigour and fertility of those plants which rapidly spread from Southampton Water, east and west along the south coast of England.

Fears were expressed at the time that the grass would block navigation ways. Small sailing channels have certainly been closed off by *Spartina* growth but there is little evidence that main navigation ways have been affected.

### *Need for control of Spartina.*

The potentialities of this species as an aid to the stabilisation and accretion of mud-flats were soon recognised. Many plantings of the grass were made on the English and European coastlines and it has been exported for this purpose to many parts of the world.

In recent years the Nature Conservancy have received several requests for advice on the control of *Spartina* (e.g. at Sand Bay in Somerset and on the Exe Estuary, Devon), and since it is also desirable to know how to control this very aggressive species in connection with the management of estuarine Nature Reserves, work on control was started in 1956 in the Bridgwater Bay Nature Reserve, Somerset.

Several holiday resorts on the Somerset coast depend for their livelihood on a free stretch of bathing beach. These beaches are often sandy at the top of the foreshore and grade very gradually out by extensive mudflats to low water mark. *Spartina* has spread from the surrounding coast onto the muddy parts of the foreshore in such places and by its subsequent growth, and its ability to catch fine silt from the retreating muddy tidal water, has spread onto the sandy areas at the top of the beach and converted the surface to silty mud.

*Spartina* may block up freshwater drainage outlets from the land, and so promote localised flooding or waterlogging of the soil in land adjacent to the upper limits of *Spartina* marsh.

There are several reasons for controlling the spread of *Spartina*

[1]Nature Conservancy Research Station, Furzebrook, Wareham, Dorset, England.

in Nature Reserves. This species can colonise all but the very lowest vegetation zones of salt marsh and can replace most of the great variety of species normally found there. It therefore reduces the variety and interest of a salt marsh. The spread of *Spartina* round the English coast has seriously limited the feeding grounds of herbiverous wildfowl (Brent goose, Widgeon, etc.) that feed on *Zostera* and *Enteromorpha* spp. Large areas covered by *Zostera*, already much reduced by disease in the 1930's, have been further depleted by the spread of *Spartina*. The *Zostera* associes contained a rich animal fauna which is not found in European *Spartina* marsh, so carnivorous wildfowl have also had their feeding grounds reduced.

*Use of herbicides on estuarine marsh.*

Herbicides have been used in inter-tidal areas in America on a limited scale. 2,4–Dichlorophenoxyacetic acid up to 27 lb/A, acid equivalent, may be needed to exterminate the estuarine marsh species *Juncus roemerianus* (4), and a combination of mineral oil at 34 gpa and 2,4,5–trichlorophenoxyacetic acid at 3 lb/A, acid equivalent, was also effective. However this species grows in the upper limits of the *Spartina* zone and is only infrequently flooded by high tides. Taylor (9) tackled the particularly difficult problem of controlling *Zostera* in submerged oyster culture areas. A heavy oily liquid consisting of a mixture of chlorinated benzenes insoluble in water and called Benoclor 3 sprayed in calm water at low tide just above the surface of the bottom at a rate of 1 gal per 800 sq ft of bottom killed all the *Zostera* plants. A test has been made with dalapon (sodium salt formulation of 2,2–dichloropropionic acid 68% acid equivalent) on *Spartina alterniflora*. Application at about 45 lb/A gave promising results at low tide, but at higher tide appeared less effective (Martin, 1955).[2]

Accidental heavy pollution of *Spartina* occurred on the Somerset coast in autumn 1955. Plants were completely blackened with a coating of oil. The following spring *Spartina* sent up a normal crop of shoots apparently none the worse. Repeated pollution with oil wastes is however reported to destroy *Spartina* in Southampton Water (Goodman, P. J.).[3]

On the advice of Dr. E. K. Woodford (Unit of Experimental Agronomy, Oxford), it was decided to try dalapon and certain substituted urea compounds; monuron (3–(*p*–chlorophenyl)–1,1–dimethylurea, diuron (3–(3,4–dichlorophenyl)–1,1–dimethylurea), and fenuron (3–phenyl–1,1–dimethylurea). These compounds are all 80% active. A combination of sodium borate and monuron known as Ureabor was also tried, as was a pelleted combination of fenuron 2,4–D and sodium borate.

*The site.*

Trials were made in a *Spartina* marsh exposed to prevailing westerly winds on the south bank of the Severn estuary. The tidal range

[2]Personal communication.
[3]Personal communication

is exceptionally high (up to 40 ft at spring tides). This enables *Spartina* to occupy a much greater vertical range (c. 12 ft) than usual, and drainage run-off is rapid.

At the level only reached by spring tides, *Spartina* grows 4 ft high on relatively level firm silty mud. Further seaward drainage channels develop, becoming 4–5 ft deep at the seaward limit of *Spartina*. In this region, growth is 1–2 ft high on firm sandy silt which is covered daily at high tide.

## PRELIMINARY TRIALS ON HIGH *Spartina* MARSH

### *Aim and layout*

Trials were first made to find out which herbicides (if any) and in what doses, would control *Spartina*. To minimise disturbance from tide a relatively uniform block of high level *Spartina* meadow about 35 yd seaward of high water mark spring tides was chosen. 5 x 5 yd plots for treatment and similar control plots were marked out parallel to the shore line and with 2 yd wide strips separating them.

### *Methods of assessment.*

On most plots the number of *Spartina* shoots, 1st year seedlings and other species were recorded in each of 10, 25 cm sq frames distributed at random within the plot before and after treatment. The mean number of *Spartina* shoots per 25 cm sq ranged from 26 to 37 in samples from 15 plots and the mean number of *Spartina* seedlings ranged from 10 to 59 in the same samples averaging 31 shoots and 33 seedlings respectively. Distribution of *Spartina* shoots is relatively uniform but seedling distribution is patchy. Visual observations were also made and a photographic record kept at various stages during the trials.

### *Results.*

Results of these trials are given in Table 1. Summer applications (1956) were made in ideal conditions with at least 14 days before the next tidal cover. Spring applications on April 10th, 1957 had only 5 days before tidal cover, but those in late April had at least 14 days before the next tidal cover.

The spring application of diuron was much more effective than summer application. Dalapon at 50 lb/A gave 80% kill of main growth 1 year after spraying, but considerable regeneration by seedlings occurred in the bare ground. A good deal of re-invasion by seedlings also occurred in the plots treaed with substituted urea compounds with the exception of fenuron. This herbicide at 40 and 60 lb/A gave 95% kill two months after spraying (Figure 1). Seedling regeneration and re-growth into the plot was inhibited in the year following treatment (Figure 2).

No significant displacement of lethal doses of herbicides to marsh surrounding plots occurred.

*Table 1.* Results of preliminary trials with herbicides on *Spartina* marsh.

| Herbicide | Date applied | Rate of application lb/A | Method of application | Period of treatment, months | Per cent kill Spartina shoots | Ratio[a] | General appearance 1–2 years after treatment |
|---|---|---|---|---|---|---|---|
| Dalapon sodium salt | Aug. 15 1956, | 20 | Sodium salt with wetting agent added, 100 gal/A as spray. | 11 | 76 | 3.0 (+) | Complete recovery in all plots 2 years after treatment through re-growth and by seedlings. |
| | | 30 | | | 48 | 2.8 (+) | |
| | | 40 | | | 84 | 2.8 +) | |
| | | 50 | | | 84 | 2.3 (+) | |
| Diuron wettable powder | Aug. 15, 1956 | 20 | 100 gal/A water suspension as spray | 11 | 9 | 0.8 (—) | Still patchy in 40 lb/A plot after 2 years, but recovering strongly. |
| | | 40 | | | 32 | 0.2 (—) | |
| | Apr. 29, 1957 | 40 | | 3½ | Visual record only | | 50–70% kill after 1¼ years. Some seedling establishment. |
| | | 60 | | | | | |
| Monuron | Aug. 15, 1956 | 20 | Pellets sprinkled by hand. | 11 | 27 | 0.9 (—) | Still patchy in 40 lb/A plot after 2 years but strong recovery and seedling growth. |
| | | 40 | | | 53 | 1.1 (+) | |
| Monuron + sodium borate | Aug. 15, 1956 | 250 | Pellets sprinkled by hand. | 11 | 69 | 7.0 (+) | 40% kill at 500 lb/A after 2 years. Poor seedling recovery. |
| | | 500 | | | 94 | 4.7 (+) | |
| | Apr. 10, 1957 | 500 | Pellets sprinkled by hand. | 3½ | Visual record only | | 20% kill at 1000 lb/A after 1¼ years, Locally strong seedling growth. |
| | | 1000 | | | | | |
| Fenuron wet. powder | Apr. 29, 1957 | 40 | 100 gal/A water suspension as spray | 3½ | 92 | 0 (—) | 99% kill at 60 lb/A after 1¼ years. Plants invading from edge, chlorotic. A few dying seedlings. |
| | | 60 | | | 96 | 0 (—) | |

[a]A ratio figure of 1 in column 7 means there is no difference in seedling growth between treated plots and controls. A figure >1 means there are more seedlings in treated plots than controls (+) and <1, less than in controls (—).

*Figure 1.* Corner of plot on high level *Spartina* marsh, July 5, 1957, 2 months after spring application of fenuron at 60 lb/A.

*Figure 2.* View of same area as Figure 1, June 10, 1958.

## SPLIT AND SINGLE DOSE DALAPON TRIAL ON HIGH *Spartina* MARSH

*Aim and layout.*

The experiment was designed to confirm that dalapon at 50 lb/A was effective against *Spartina* and to compare the effects of a single dose with a split dose of 20 + 30 lb/A put on with an intervening period of 3 weeks. The layout was a latin square design of 9 plots including controls each of 6 x 4 yd with a 1 yd wide path between plots. The site was about 10 yd to seaward of the first trial site. Results were assessed in the way outlined above for preliminary trials.

*Results.*

Spraying (July 3rd, 1957) was carried out 1 month earlier than the previous year's trial, under calm dry conditions. The tide was not expected to reach the seaward plots for at least 10 days and the landward ones for about 3 weeks.

1 year after application no significant difference was found between plots which had received the single dose and those which had received the split dose. In both there was 100% kill of main growth *Spartina* (Table 2). 1958 was a poor year for *Spartina* seedlings and regeneration in the two sprayed plots was similar, and only slightly higher than in controls.

*Table 2.* Mean shoot and seedling nos./25cm sq sample in trial plots, before and after summer application of dalapon on *Spartina* marsh.

| Species | Control | | | | | | 20 + 30 lb/A split dose | | | | | | 50 lb/A single dose | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1957 | | | 1958 | | | 1957 | | | 1958 | | | 1957 | | | 1958 | | |
| Spartina shoots | 22 | 16 | 22 | 30 | 21 | 29 | 29 | 19 | 23 | 0 | 0 | 0 | 28 | 17 | 18 | 0 | <1 | 0 |
| Spartina 1st year seedlings | 170 | 280 | 250 | 30 | 9 | 34 | 350 | 300 | 200 | 33 | 28 | 41 | 180 | 250 | 270 | 22 | 28 | 41 |
| Salicornia stricta | 100 | 140 | 49 | 6 | 1 | 3 | 84 | 44 | 28 | 17 | 33 | 30 | 65 | 25 | 39 | 22 | 14 | 18 |

## TIDAL TRIALS WITH DIFFERENT FORMULATIONS OF FENURON

*Aim and layout.*

Aims of this trial were to find out if *Spartina* could be killed in middle and lower zones of the sward, to find out to what extent the tide dispersed lethal doses of the herbicides outside the plot areas and to compare different methods of applying them.

Highest lying plots on level marsh were 100 yds seaward of high water mark spring tides (Zone 1). Lowest plots (Zone 7) were about 20 yds landward of the seaward limit of *Spartina*, on marsh dissected by channels 1½ ft wide and 2 ft deep. Plots 6 x 4 yds were used (in one case, 2 x 5 yds) and a maximum of 5 plots were spaced at 30 yd intervals from Zone 1 to Zone 5 for each treatment. Since there was no information about the toxicity of these herbicides to other marine organisms and it was not known to what extent they might spread outside the plot areas, low dosages were used (Table 3).

*Table 3.* Results of herbicide applications in middle and lower zones of *Spartina* marsh.

| Date of application | Method of application | Material | Actual fenuron dosages lb/A | Zones treated (1–landward, to 5–seaward) | Per cent kill 1 year after treatment in zone | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 | 4 | 5 |
| Apr. 25, 1958 | Sprayed | Non-activated fenuron | 40 | 3, 5 | | | 35 | | <10 |
| | | Activated fenuron | 5 | 1, 4, 5 | 0 | | | 0 | 0 |
| | | | 10 | 1, 2, 3, 4, 5 | 0 | 0 | 0 | 0 | 0 |
| | | | 20 | 1, 2, 3, 4, 5 | <5 | 10 | <10 | <10 | 0 |
| Apr. 25, 1958 | Pelleted 1. Sprinkled on surface | Fenuron + 2,4–D + sodium borate | 15 | 1, 3, 4, 5, | 45 | | 45 | 25 | 65 |
| | 2. Injected into mud | Fenuron + 2,4–D + sodium borate | 15 | 1, 3, 4, 5 | 35 | | 50 | 70 | 60 |
| | | | 20 | 3, 5 | | | 45 | | 99[a] 10 |

[a]Uneven application, half plot showing 99 per cent kill, other half 10 per cent kill.

Fenuron was not readily obtainable in England at the time of the trials and available formulations had to be used. These included ordinary fenuron and activated fenuron as 5% emulsifiable concentrates each containing ½ lb fenuron per gal. In addition, a pelleted combination of fenuron, 2,4–D and sodium borate, the only pelleted form of fenuron available, was tried. This formulation contained 3.5% fenuron (100% active) and 5% 2,4–D. The pelleted material was put on in two ways (1) by sprinkling manually on to the mud surface and (2) by poking a grid of small holes (5–10 cm deep and c. 2cm diam) in the mud of the plots, tipping regular amounts of the material into them and then closing over the tops of the holes by stamping on them. Fenuron sprays, both activated and non-activated, were applied at 100 gal/A.

*Results.*

Only photographic and visual observation records were made of these plots.

All treatments were made on April 25, 1958 just after high water neaps. This tide covered the bottom two plots (Zones 4 and 5) and it was expected that Zone 5 at least would be covered daily by the tide from the time of treatment and that all plots would be submerged within one week from the time of treatment.

Useful results were obtained (Table 3) even at the low dosages used. Kill was most effective in the wetter low-lying parts of plots. Although this was probably partly due to washing down and concentration of herbicides, results from pelleted applications show that seaward plots were more affected by fenuron than landward ones. This suggested that wetness aided the action of herbicides in spite of increased tidal action. The reverse was true of sprayed plots and tidal action was probably decisive in reducing the effect of sprays in seaward plots.

No lethal doses of herbicides were displaced to marsh outside any plots in spite of regular tidal cover in the seaward plots.

## DISCUSSION

In addition to the vagaries of the weather at and immediately after spraying there is the further complication of the effect of tides in diluting herbicides on *Spartina* marsh. Dalapon at 50 lb/A for example gave 80% kill of main growth in the 1956 trials and 100% kill of main growth in the following year's trials. This suggests that the results of any single series of trials should be treated with caution. However, the 1957 trials were done in July, one month earlier than those in 1956. In July *Spartina* is just coming into flower and like *Phragmites* (8) it may be most susceptible to dalapon at this stage. Conditions for seedling establishment are exceptionally good at Bridgwater Bay compared with those on *Spartina* marshes of south and east coasts. However good seeding years do not occur regularly (Table 2), and good control in higher marsh was achieved when a successful application of dalapon at 50 lb/A was followed by a poor seed year. Large scale spraying would of course seriously

reduce seed potential for re-invasion in any case. Since dalapon is only one-third the cost of fenuron it is worth considering for control in the higher regions.

Split dosage applications of dalapon on *Spartina* was no more effective than a single dose. However split applications have proved more effective than single applications using dalapon for the control of *Agropyron repens* (L.) Beauv. (7).

When *Spartina* marsh is opened up in the higher levels by dalapon spraying at Bridgwater Bay, the annuals *Atriplex hastata* L. and *Salicornia stricta* Dum. invade the bare mud in addition to *Spartina* seedlings. These plants give an interesting indication of the succession that follows the removal of *Spartina* in the area (2).

Results using substituted area herbicides were surprising in that fenuron gave much better control than monuron either alone or in combination with borate. Fenuron is much more soluble than this compound and also has much lower inherent toxicity than monuron (1). However, it has been demonstrated (5), that in certain soils, e.g. clay loam, fenuron may be as toxic as monuron. The greater solubility of fenuron probably helps it to reach the roots of *Spartina* through the marsh silt more readily than monuron. This might explain the greater effectiveness of pelleted fenuron in the wettest plots lying near the seaward limit of the marsh.

Monuron is adsorbed by soil in increasing amounts as the organic matter and clay content rises (6). The upper levels of the marsh are low in organic matter (3% organic carbon), but rich in silt and clay (90%). The lower marsh has only 2% organic carbon and is more sandy (32% silt and clay). Thus although the organic matter can play little part in reducing toxicity by adsorption in these soils, the high silt and clay content probably does.

There is no direct information about the rate of breakdown of these herbicides in saline muds. In land soils this is attributed mainly to micro-organisms (3). Breakdown is certainly quite slow in the case of fenuron for it was still lethal to seedlings 1½ years after application. Measurements indicate that there is annual accretion of at least 2 cm on these marshes in the *Spartina* zone. This should allow seedling establishment in the trial plots 3 or 4 years after treatment even if fenuron is still active in the mud after that time, for the lethal zone is gradually being buried. In a successful large scale treatment of *Spartina* marsh with soil sterilants, however, a certain amount of surface mud erosion might be expected and possible side effects of this kind need to be studied.

Although the mammalian toxicity of substituted ureas and dalapon is low there is no information about the effects of these substances on marine invertebrates. *Spartina* marsh in this country seems to have few associated animals compared with *Zostera* marsh, perhaps because there has not yet been time for a fauna to become adapted to its environment. A few mud cores examined, produced only one or two arthropod larvae, but live larvae were found in the plot treated with fenuron at 60 lb/A.

Removal of *Spartina* by digging it out is costly and not effective.

Although the use of granular fenuron is also expensive it is certainly effective even at the lowest limits in the marsh studied, and could be applied over large areas by air. Whether or not *Spartina* can be controlled successfully by the means described on the soft mud marshes of our south and east coasts remains to be seen.


## SUMMARY

Dalapon at 50 lb/A gave 100% kill of *Spartina* main growth one year after spraying when spray was applied in July to the upper levels of inter-tidal marsh in the Nature Reserve at Bridgwater Bay, Somerset. Re-invasion by seedlings suggests that repeated applications may be necessary if a limited area is being controlled.

Fenuron at 40 lb/A gave 99% kill in the same region when applied as a spray in April. There was no significant re-growth in plots, or new seedling establishment 1½ years after spraying.

A pelleted combination of fenuron, 2,4–D, and sodium borate injected into the mud or sprinkled on the surface at 15 lb/A, gave a 60% kill in *Spartina* marsh reached daily by the tides.

The problem of *Spartina* control in relation to some Nature Conservation problems and the significance of the results of these trials is briefly discussed.



## ACKNOWLEDGEMENTS

We are most grateful to Dr. E. K. Woodford, Unit of Experimental Agronomy, Oxford University, for useful advice, the loan of a knapsack sprayer and for the gift of dalapon for the trials. Dr. G. G. Fisher, Chesterford Park Research Station, (Fisons Ltd.) kindly provided us with samples of monuron, fenuron and diuron. Mr. J. W. Harper and Mr. D. Montgomery of Borax Consolidated, London, provided the pelleted formulation of fenuron, 2,4–D, and borate and we are also grateful to them for useful advice. Mr. J. House, part time Warden of the Bridgwater Bay Nature Reserve kindly provided facilities for us on the site. We also have pleasure in acknowledging the support of Mr. E. L. Kelting, O.B.E., Chief Engineer of the Somerset River Board through whose good offices the Nature Reserve at Bridgwater Bay was obtained under a management agreement with the Somerset River Board.


## LITERATURE CITED


1. ABEL, A. L. The substituted urea herbicides. Chemistry and Industry No. 33:1106–1112. 1957.
2. DAY, B. E., and SWEZEY, A. W. Control of *Phragmites* with dalapon. Down to Earth, 11(4):17–19. 1956.
3. HILL, G. D., MCGAHEN, J. W., BAKER, H. M., FINNERTY, D. W., and BINGEMAN, C. W. The fate of substituted urea herbicides in agricultural soils. Agron. Journ. 47:93–104. 1955.
4. MARTIN, A. C. Improving duck marshes by weed control. U.S. Fish & Wildlife Service Circular 19. 1953.
5. SHEETS, T. J., and CRAFTS, A. S. The phytotoxicity of four phenylurea herbicides in soil. Weeds 5:93–101. 1957.

6. SHERBURN, H. F., and FREED, V. H. Soil effects on herbicides: adsorption of 3(*p*–chlorophenyl)–1,1–dimethylurea as a function of soil constituents. J. Agric. and Food Chem. 2:937–939. 1954.
7 SOUTHWICK, L. New leads from recent field research with dalapon. Down to Earth 11(3):6–7. 1955.
8. STEENIS, J. H., WILDER, N. G., COFER, H. P., and BECK, R. A. The marshes of Delaware, their improvement and preservation. Delaware Board of Game and Fish Commissioners. Pittman-Robertson Publ. No. 2. 1954.
9. TAYLOR, A. R. A. Control of eelgrass in oyster culture areas. Fisheries Research Board of Canada. General series Circular No. 23. 1954.

---

*Addendum*

Since this paper was submitted pilot trials on east coast *Spartina* in the Nature Reserve at Scolt Head Island, Norfolk, have shown that both the pelleted formulation of fenuron (referred to above), used at a dose of 50 lb/A, and Ureabor at 2000 lb/A have given 100% kill in areas subject to daily tidal immersion.

# Periderm Formation in Hypocotyl of *Gossypium hirsutum* L. and its Effect upon Penetration of an Herbicidal Oil

R. D. Palmer[1] and W. B. Ennis, Jr.[2]

## Introduction

In using non-fortified oils for post-emergence weed control in cotton, it has been necessary to follow certain precautions because of differential plant response at different stages of cotton growth. Several workers (2) emphasize that certain oils can be applied safely to young cotton hypocotyls three weeks after emergence, but as soon as small bark cracks begin to appear at the base of the stem, oil usually causes injury. Palmer and Ennis (7) found that when an oil[3] was applied to cotton stems 14 to 80 days old, it injured the stem, and reduced final yields when cotton was 27 to 59 days old at time of application. Plants less than 27 days old and more than 59 to 80 days old were not injured by the oil.

This study was undertaken to investigate the relation of the morphological development of the cotton hypocotyl and its susceptibility to oil. The selectivity of the oil for certain tissues of the hypocotyl was examined.

## Literature Review

Baranov (1) and Webber (10) reported on the arrangement of the primary permanent tissues in the hypocotyl of *Gossypium*. Webber (10) pointed out that as the hypocotyl grew older the epidermis became underlain by periderm which later replaced the epidermis. The phellogen which gives rise to the periderm forms in the outermost layer of the cortical cells. At different ages the periderm of any given species differs somewhat in appearance.

The distinct processes involved in the toxic action of an herbicidal oil are (1) penetration of the cuticle, or surface, and (2) reaction with the protoplasm or cell structure. Dallyn (3) and Dallyn and Sweet (4) reported that oils of Stoddard Solvent type rapidly penetrated the cells of beans. The oil caused the breakdown of the physical organization of the protoplasm, and finally the entire leaf structure collapsed. Minshall and Helson (6) suggested that oil killed susceptible plant cells by disrupting water relations, which in turn affected transpiration and other processes. van Overbeek and Blondeau (9) reported on the theory of oil action. They stated that the

[1]Formerly Graduate Assistant, presently Assistant Plant Physiologist, Department of Plant Pathology and Physiology, Mississippi Agricultural Experiment Station, Mississippi State University, State College, Mississippi.

[2]Formerly, Head, Department of Plant Pathology and Physiology, Mississippi Agricultural Experiment Station; presently Chief, Crops Protection Research Branch, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland.

[3]Aromatic content 22 to 24 percent, boiling range 300° to 400° F., unsaturated compounds 0.5 to 1.0 percent, sulfur compounds 0.25 to 0.30 percent, and a maximum aniline point to 128° F., marketed under the trademark name "Lion No. 1".

micellar structure of the plasma membrane allows the hydrocarbons to dissolve into it, and the oil molecules displace the fatty molecules of the cell membrane. Kinetic energy apparently interrupts the close alignment of the fatty molecules, allowing the oil molecules to slip between them and causing a leak in the cell membrane. The authors theorized that when these leaks become more abundant the permeability increases to the point where larger molecules leave the cell; thus semipermeability is lost and the cell collapses.

## MATERIALS AND METHODS

The test plants used in this study were grown under field conditions. The variety of *Gossypium hirsutum* L. was Coker 100-W, American upland. The post-emergence oil[4] was applied on the hypocotyls at 8 gal/A. The nozzle was set so that the spray fan was horizontal, and oil struck the cotton stem no higher than 1 inch from the ground level.

The first treatment was made 14 days after emergence of the plants and at two-day intervals thereafter until 80 days after emergence. Gross morphological responses were recorded and reported previously (7).

Hypocotyls of 27-, 36-, 50-, and 62-day-old cotton plants were observed to have a wide range of tolerance to the oil. Plants of these ages were selected for the anatomical studies. Immediately before treatment and 7 days after treatment, representative segments of the hypocotyls were selected and fixed in FAA (formalin, acetic acid, and ethyl alcohol). The segments were prepared for microscopic examination by dehydration through an ethyl to butyl alcohol series, embedded in paraffin (M. P. 56 to 59°C), sectioned at 15 microns by means of a rotary microtome, and stained with an aqueous solution of crystal violet and erythrosin. After the sections were mounted in balsam, photomicrographs were made.

## EXPERIMENTAL RESULTS

*Periderm formation in the hypocotyl.* The 27-day-old hypocotyl had a continuous epidermis (Figure 1A). The outermost cortical cells showed numerous intercellular spaces. The cork cells were initiated by periclinal divisions of the cork cambium (periderm) in the sub-epiderminal parenchyma of the cortex as illustrated in Figure 1A.

The most striking change in the anatomy of 27- to 36-day-old hypocotyl was the development of cork layers and the accompanying rupture of the epidermis (Figure 1A, B). Dense cytoplasm appeared in certain cells of the cortex and in the phellem, phellogen, and phelloderm as manifested by dark staining of these cells (Figure 1B, C, D). More cork (phellem) layers developed as the plants grew older.

[4] *Loc. cit.*[3]

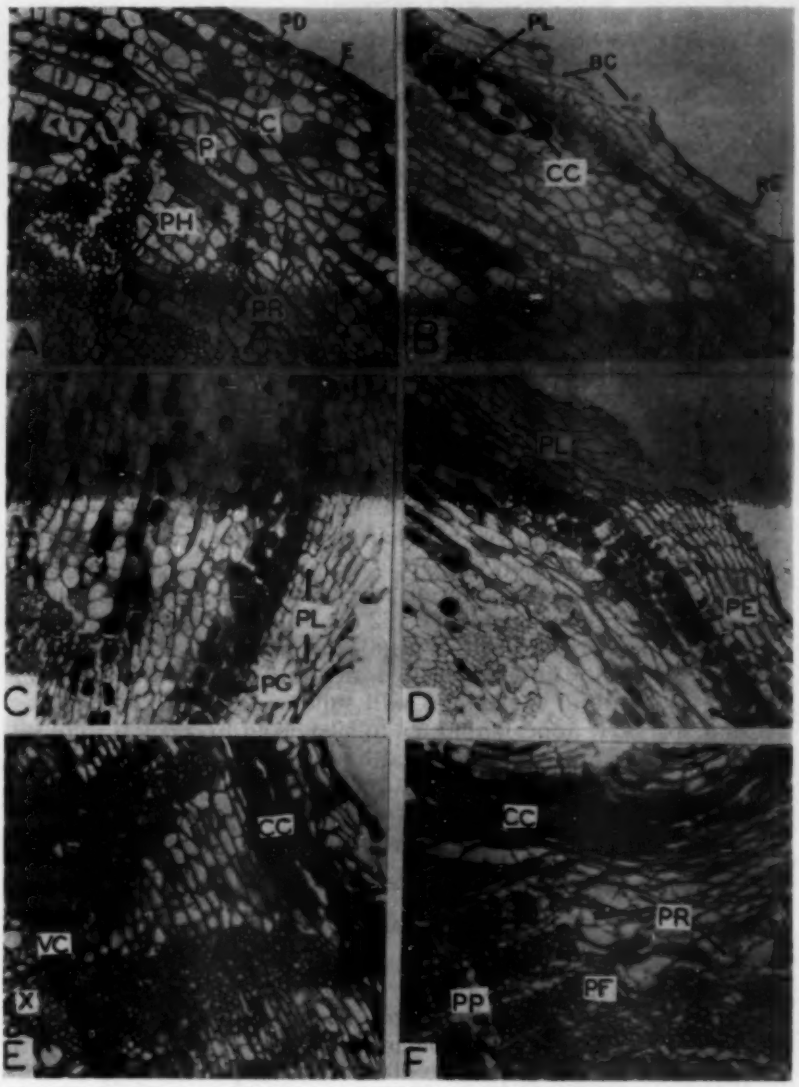



*Figure 1.* Cross sections of the hypocotyls of *Gossypium hirsutum* L. (× 100). *A.* (untreated) 27 days old. *B.* (untreated) 36 days old. *C.* (untreated—check to *E* and *F*, below) 50 day old. *D.* (untreated) 62 days old. *E* and *F* (treated) 57 days old (7 days after treatment). BC, barkcrack; C, cortex; CC, cork cambium; P, pericycle; PD, periclinal division; PE, phelloderm; PF, phloem fibers; PG, phellogen; PH, phloem; PL, phellem; PP, phloem parenchyma; PR, phloem ray; RE, ruptured epidermis; VC, vascular cambium; X, xylem.

Hypocotyls 36 to 50 days old were very susceptible to the oil. The 62-day-old hypocotyl (Figure 1D) was resistant to oil and showed two or three more cork layers than the hypocotyl 36 to 50 days old (Figure 1B, C). The cells of the cork cambium in 36- to 50-day-old hypocotyls appeared to be larger in volume and very active in cork development, whereas the cells of the cork cambium in 62-day-old hypocotyls were smaller and probably less active in cork development.

*Anatomical responses.* Hypocotyls 57 days old (7 days after treatment), (Figure 1, E and F) were selected to show typical tissue responses to the oil. The oil appeared to have killed the cortical parenchyma (phloem ray), cork cambium, phloem parenchyma, and vascular cambium in the hypocotyl. The degree of damage to these tissues depended upon the quantity of oil which penetrated into the tissue. The phellem, xylem, and phloem fibers were apparently unharmed by the oil, because these tissues appeared to have retained their normal shape.

## DISCUSSION

A relation between the morphology of the cotton hypocotyl and its susceptibility to injury by an herbicidal oil was found. In the young hypocotyl an unbroken epidermis acted as an effective barrier to oil penetration. In older hypocotyls (62 days old) resistance was due to oil-impervious cork layers. Sifton (8) and Esau (5) stated that cork cells are generally impervious to water and resistant to oil penetration, especially if the cork is well suberized and free from intercellular spaces. It appears that 36- to 50-day-old hypocotyls were susceptible to the oil because (1) the bark cracks with few cork cells served as a channel for the oil to penetrate, and (2) the oil penetrated into the active cork cambium, phloem parenchyma, and vascular cambium and exerted an action which destroyed these vital tissues.

## SUMMARY

Anatomical studies were undertaken to determine the effect of age of the cotton hypocotyl upon its response to an herbicidal oil. The young hypocotyl was resistant to oil because of the protection afforded by the unbroken epidermis. However, as the hypocotyl grew, cork cracks were produced in the stem primarily as a result of secondary growth of the cork cambium (periderm). The superficial cork cracks formed prior to the development of cork layers. These cracks served as a place for oil to collect and provided a point of entrance. From this point of entrance the oil moved through intercellular spaces. The cork cambium, phloem parenchyma, vascular cambium, and cortical parenchyma were destroyed by the oil. Cork cells, phloem fibers, and xylem were apparently tolerant to the oil. The vital tissues of older hypocotyls were protected by cork layers which apparently were impervious to the oil.

## LITERATURE CITED


1. BARANOV, P. A. The structure and development of the cotton plant. Ogis-Isogis, Moscow. 1937.
2. BINGHAM, S. W., EASLEY, T., EDWARDS, F. E., HARRIS, V. C., HOLSTUN, J. T., JR., NORMAND, W. C., and WOOTEN, O. B., JR. Weed control recommendations. Mississippi Agric. Expt. Sta. Bul. 556. 1958.
3. DALLYN, S. Herbicidal action of oils. N. Y. Agric. Expt. Sta. Memoir 316:1–43. 1953.
4. ———, and SWEET, R. D. Theories on the herbicidal action of petroleum hydrocarbons. Proc. Amer. Soc. for Hort. Sci. 57:347–354.
5. ESAU, K. Plant Anatomy. John Wiley and Sons, Inc., New York. 1953.
6. MINSHALL, W. H., and HELSON, V. A. The herbicidal action of oils. Proc. Amer. Soc. for Hort. Sci. 53:294–298. 1949.
7. PALMER, R. D., and ENNIS, W. B., JR. The effect of age of cotton upon its response to an herbicidal oil applied as a directed spray. Proc. SWC 6:106–115. 1953.
8. SIFTON, H. B. Air space in plants. Bot. Rev. 11:108–143. 1954.
9. VAN OVERBEEK, J., and BLONDEAU, RENE. Mode of action of phytotoxic oils. Weeds 3:55–65. 1954.
10. WEBBER, I. E. Anatomy of the leaf and stem of *Gossypium*. J. Agr. Res. 57:269–286. 1938.

# Control of Bedstraw *(Galium mollugo)* with Alpha-Phenoxypropionic Acid Derivatives[1]

JAL S. PARAKH and MARVIN M. SCHREIBER[2]

## INTRODUCTION

BEDSTRAW *(Galium mollugo* L.) is a deep-rooted perennial weed present throughout New York and many areas of the northeastern United States and Europe. It occurs in pasture, meadows, waste areas and along ditch banks and roadsides. This weed assumed importance comparatively recently and almost concurrently with the increasing popularity and widespread use of birdsfoot trefoil *(Lotus corniculatus* L.).

Many factors contributed to the increased prevalence of bedstraw, particularly in areas where it was present but of little consequence. Birdsfoot trefoil seedings, usually left down for several years, enabled bedstraw, a strong competitive weed which propagates from seed and rootstalks, to become well entrenched.

Bedstraw growing in pastures is usually avoided by grazing animals, thus enabling it to reproduce and disseminate seed. Probably one of the most important reasons for the marked increase of bedstraw on ditch banks and along roadsides has been its resistance to the 2,4–dichlorophenoxyacetic acid (2,4–D) and 2,4,5–trichlorophenoxyacetic acid (2,4,5–T) herbicides generally used on those areas. The main objective of the experiments reported in this paper was to find one or more herbicides that would completely eradicate bedstraw, thus allowing spot treatments where desirable in crop areas and for general use in non-crop situations. A second objective was to find a method of using an eradicant to selectively remove bedstraw in birdsfoot trefoil fields.

## LITERATURE REVIEW

*Bedstraw.*

Among the commoner species of *Galium* in the United States, namely *G. aparine, G. boreale, G. asprellum, G. verum,* and *G. mollugo,* the latter is one of the most widespread and perhaps one of the most important as a weed. All the species listed except *G. aparine* are long-lived perennials.

Established plants of *G. mollugo* have several stems arising from a crown-like clump, which can attain a diameter of from 10 to 24 inches. Erect stem-growth starts early in the spring and continues until the stems reach a height of about 15 to 24 inches, when, because

---

[1]Cooperative investigation between the Department of Agronomy, New York State College of Agriculture, Ithaca, N. Y., and the Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture as Agronomy Paper No. 470, Cornell University.

[2]Former Graduate Assistant, Department of Agronomy, Cornell University, Ithaca, N. Y., and Research Agronomist, Crops Research Division, Agricultural Research Service, United States Department of Agriculture. Present address of Junior author, Dept. of Bot. & Pl. Path., Purdue Univ., Lafayette, Indiana.

of weakness, they lodge and form a very dense mat. Growth usually continues until they reach a length of about 4 feet. In New York, bedstraw first blooms in May to June and again in late July and August if first growth is cut.

Kinne[3] observed that bedstraw has a coarse, fibrous deep root system with a dense mass of fine roots near the surface of the soil, just below the crown. Thick woody rhizomes spread laterally and vertically from the crown. The roots are reddish orange, and the rhizomes are a lighter orange in color.

A detailed anatomical study of the plant was made by Korsmo (13).

*Alpha-phenoxypropionic acids.*

Among the first of the original phenoxycompounds tested was 2–(2,4–dichlorophenoxy)propionic acid [2–(2,4–DP)]. Using cuttings of several plant species as test objects, Hitchcock and Zimmerman (10) in 1942 found that in general 2–(2,4–DP) was about 30 times as effective as 2,4–D and 10 times as effective as naphthalene acetic acid (NAA) in inducing rooting of cuttings.

Subsequently, Hitchcock and Zimmerman (11, 12) compared the root-inducing activity of 63 phenoxy acids. The most active compounds, inducing 15 to 40 roots per cutting, were 2,4,5–T, 2–(2,4,5–trichlorophenoxy)propionic acid (silvex), 2–(2,4–DP), and 2–(2,4–dibromophenoxy)propionic acid. However, only 2,4,5–T and silvex possessed activity comparable with that of NAA, which was used as a standard.

Thompson, Swanson and Norman (21) summarized the growth-inhibitory activities of over 1000 organic compounds on the basis of the corn-germination tests, Kidney bean single-droplet water test, and Kidney bean single-droplet oil test and found various alpha-phenoxypropionic acids to be highly active compared with 2,4–D. Similar evaluation by Fults and Payne (8) showed silvex and other alpha-phenoxypropionics to be superior to 2,4–D over a wide range of concentrations.

Thus during 1942–1947, the growth-regulating activity of the alpha-phenoxypropionic acid derivatives, especially 2–(2,4–DP) and silvex, was firmly established. Yet, it was not until the realization of the limitations of 2,4–D, 2–methyl–4–chlorophenoxyacetic acid (MCPA) and 2,4,5–T in situations where the phenoxyacetic compounds were shown to be non-selective and of low herbicidal activity that reappraisal of the alpha-phenoxypropionics took place, some 5 years later.

*Agricultural uses of alpha-phenoxypropionics.*

The use of the alpha-phenoxypropionic acid derivatives in and on horticultural crop plants to induce parthenocarpic setting of fruits, inhibition of leaf and fruit drop, hastening maturity and

[3]Kinne, E. A. Preliminary studies of the control of smooth bedstraw *(Galium mollugo* L.) in birdsfoot trefoil *(Lotus corniculatus* L.). Master of Science Thesis, Cornell University. 1955.

ripening of fruits and root initiation has been known and practiced since 1944. Since this phase is immaterial to the present study and the literature is voluminous, no review of these investigations will be presented in this paper.

The early work of Elwell (5) and Elwell et al. (6) conclusively showed the greater activity of silvex over 2,4,5–T on many of the harder-to-kill woody species as well as herbaceous plants. This coupled with the results of Fisher, Behrens and Watson (7) demonstrating less injury to cotton from silvex than from 2,4,5–T led the way to extensive testing in all parts of the country (2, 3, 4, 9, 18, 22).

Only recently the use of silvex for the control of aquatic weeds was reported to be highly successful (19, 23).

The work of Lush (15), Leafe (14), Selleck and Coupland (16) and Shaw and Gentner (17) resulted in the control of many herbaceous broadleaf weeds by the use of the alpha-phenoxypropionic acid derivatives. Some of the data suggest possible selective control in small grains (14, 17) but severe injury to most forage legumes (17).

*Chemical control of bedstraw.*

Extensive field trials by Kinne[4] to control bedstraw resulted in failure with the herbicides commercially available in 1953. Only 4,6–dinitro–o–sec–butylphenol (DNBP) showed top-kill followed by new regrowth. Initial trials between 1954 and 1956 with 2,2–dichloropropionic acid (dalapon) appeared more promising but again regrowth occurred because of lack of root-kill.[5] Aberg (1), trying to control *G. mollugo* and *G. aparine* in non-crop land areas in Sweden, found that 2,4,5–T showed some promise.

The only reports in the literature on the control of a bedstraw species *(G. aparine)* were made by Leafe (14) and Lush (15), who used 2–(2–methyl–4–chlorophenoxy)propionic acid [2–(MCPP)] and 2–(3–methyl–2,4–dichlorophenoxy)propionic acid. *Galium aparine*, an annual in small grains, was successfully controlled by both phenoxypropionics at 2 pounds per acre.

## MATERIALS AND METHODS

*Preliminary greenhouse screening.*

Bedstraw and birdsfoot trefoil plants, grown from seed in wooden flats in the spring of 1956, were transplanted into 6-inch clay pots in late July so that there would be five plants of either species per pot. The plants were allowed to establish themselves in the pots for 1 month, at which time they were cut to a height of 5 inches to obtain uniformity. Replicated treatments were applied on September 11, 1956, with an experimental sprayer developed by Terry (20). The herbicides, rates of application and dates of visual observations of foliar and root injury are shown in Table 1. All rates expressed in all experiments reported are on an acid-equivalent basis.

*Field experiments.*

The field used for all experiments reported in this paper, located

[4] *Loc. Cit.*

[5] Schreiber, M. M. Unpublished data, 1954–1956.

in Ithaca, N. Y., was seeded to Empire birdsfoot trefoil in 1951. Because of contamination with bedstraw seed, within 2 years the field had approximately equal numbers of bedstraw and birdsfoot trefoil plants. Several species of broadleaf weeds and grasses were also present.

A randomized split-plot design was used for all field experiments. The number of replicates varied from 2 to 4 for individual experiments. All plots were 6 by 32 feet with 10-foot alleyways between whole-plots and replications. All treatments were applied in 30 gal/A of water with a tractor sprayer especially converted for spraying 6-foot plots. Each herbicide was applied starting with the lowest concentration and progressing to the highest. With each change of chemical, the spray equipment was thoroughly rinsed with 5 gallons of 1 percent ammoniated water followed by 5 gallons of water.

Data obtained consisted of (a) periodic stand counts of bedstraw and birdsfoot trefoil, (b) yields (pounds of dry weight per acre) for first and second cuttings, (c) botanical composition from second cuttings by hand separation, and (d) continuous observation of birdsfoot trefoil stunting and recovery as well as broadleaf weed encroachment.

Because of the nature of the bedstraw plant, the most effective method of determining stands was to count all bedstraw clumps in a 96 square foot area in the center of each plot. When two or more clumps grew close together, they tended to merge into one large clump as the season progressed. It was, therefore, necessary to make several independent counts early in the spring and soon after each cutting. The additional counts also offered the opportunity of studying regrowth. Analyses of variance were carried out on all data obtained.

The herbicides used, rates of application, time of application, stage of growth at time of application, and dates of observation are shown in Tables 2 to 6 for the four field experiments reported.

## RESULTS AND DISCUSSION

*Preliminary greenhouse screening.*

All treatments caused initial discoloration of the foliage of bedstraw and to some extent of birdsfoot trefoil. The foliage changed from dark green to light green to yellow and finally to brown within a 3 week period (Table 1 and Figure 1). The 7½ lb/A rate of all the amine salts tested—2–(2,4–DP), 2–(MCPP) and silvex—and the 2½ lb/A rate of 2–(2,4–DP) caused complete kill of bedstraw foliage and roots. Although the injury to birdsfoot trefoil was more serious at the high rate of amines, little foliage or root kill was observed with any material. None of the 2½ lb/A rates of the amine salts tested caused death of birdsfoot trefoil roots.

The esters at all rates tested caused 100 percent kill of both bedstraw foliage and roots. However, in spite of severe foliage kill of birdsfoot trefoil by all rates of the esters, only the 10 lb/A rate caused appreciable kill of the roots. It was evident that at the same rate of application the esters were more effective for bedstraw control than the amine salts.

*Table 1.* Foliage and root-kill of bedstraw (B) and birdsfoot trefoil (T) effected by an alkanolamine salt and various ester formulations of chlorinated alpha-phenoxypropionic acids in greenhouse tests sprayed September 11, 1956. Each value based on 2 replications.

| Formulation, herbicide and rate, lb/A | Per cent foliage killed on | | | | | | Per cent roots killed on | |
|---|---|---|---|---|---|---|---|---|
| | Oct. 10 1956 | | Nov. 20, 1956 | | Dec. 25, 1956 | | Dec. 25, 1956 | |
| | B | T | B | T | B | T | B | T |
| 0 (check) | 0 | 0 | 10[a] | 10[a] | 10[a] | 15[a] | 0 | 0 |
| 2–(2,4-DP), amine: | | | | | | | | |
| 2½ | 100 | 5 | 100 | 15 | 100 | 15 | 100 | 0 |
| 7½ | 100 | 15 | 100 | 50 | 100 | 50 | 100 | 10 |
| 2–(MCPP), amine: | | | | | | | | |
| 2½ | 75 | 15 | 80 | 15 | 80 | 15 | 60 | 0 |
| 7½ | 100 | 55 | 100 | 80 | 100 | 80 | 100 | 30 |
| Silvex, amine: | | | | | | | | |
| 2½ | 95 | 10 | 100 | 20 | 100 | 25 | 90 | 0 |
| 7½ | 100 | 10 | 100 | 75 | 100 | 75 | 100 | 10 |
| Silvex, propylene glycol butyl ether ester: | | | | | | | | |
| 5 | 100 | 40 | 100 | 80 | 100 | 100 | 100 | 20 |
| 10 | 100 | 60 | 100 | 100 | 100 | 100 | 100 | 90 |
| Silvex, iso-octyl ester: | | | | | | | | |
| 2½ | 100 | 50 | 100 | 90 | 100 | 100 | 100 | 20 |
| 10 | 100 | 80 | 100 | 100 | 100 | 100 | 100 | 90 |

[a]Excessive greenhouse temperature.

*Figure 1.* Bedstraw and birdsfoot trefoil plants treated with 2½ lb/A of alkanolamine salt of 2–(2,4–DP). Left: treated bedstraw plants with all foliage and roots dead and foliage brown. Right: treated birdsfoot trefoil plants showing slight foliage burn and initial stunted growth but dark-green and plants recovering. Plants treated September 11, 1956 and photographed October 10.

The initial greenhouse screening test showed conclusively that bedstraw could be eradicated by use of the chlorinated alpha-phenoxypropionic acids. However, bedstraw plants grown in pots would be considered young plants in relation to the well-established plants normally found in the field.

*Field trials, fall application of amine salts.*

The data in Table 2 show the effects of fall applications of amine salts of 2–(2,4–DP), silvex, and 2–(MCPP) on stands of bedstraw and birdsfoot trefoil. The analysis of variance of the stand data showed highly significant differences for rates but no significant

*Table 2.* Stands of bedstraw (B) and birdsfoot trefoil (T) as affected by application of alkanolamine salts of 2–(2,4–DP), silvex and 2–(MCPP) on November 17, 1956[a]. Each value based on 3 replications.

| Herbicide and rate, lb/A | Number of plants in 96 sq ft on | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Nov. 14, 1956 | | May 7, 1957 | | July 19, 1957 | | Sept. 19, 1957 | |
| | B | T | B | T | B | T | B | T |
| 2–(2,4–DP) | | | | | | | | |
| 0 | 16 | 24 | 27 | 27 | 36 | 35 | 32 | 30 |
| ½ | 29 | 22 | 33 | 26 | 44 | 26 | 36 | 27 |
| 1 | 15 | 26 | 13 | 27 | 17 | 33 | 21 | 27 |
| 2 | 27 | 18 | 18 | 18 | 31 | 31 | 25 | 34 |
| 4 | 17 | 28 | 0 | 17 | 1 | 30 | 2 | 30 |
| 8 | 13 | 22 | 0 | 4 | 5 | 17 | 3 | 30 |
| Silvex | | | | | | | | |
| 0 | 23 | 26 | 30 | 22 | 44 | 28 | 35 | 30 |
| ½ | 23 | 21 | 30 | 25 | 38 | 29 | 33 | 25 |
| 1 | 27 | 19 | 23 | 24 | 33 | 33 | 33 | 24 |
| 2 | 24 | 16 | 11 | 21 | 17 | 33 | 19 | 30 |
| 4 | 22 | 22 | 0 | 23 | 2 | 37 | 4 | 40 |
| 8 | 24 | 24 | 0 | 23 | 3 | 29 | 2 | 35 |
| 2–(MCPP) | | | | | | | | |
| 0 | 24 | 21 | 35 | 17 | 44 | 25 | 38 | 29 |
| ½ | 28 | 29 | 29 | 16 | 41 | 22 | 39 | 24 |
| 1 | 24 | 21 | 23 | 19 | 39 | 28 | 37 | 29 |
| 2 | 25 | 18 | 14 | 14 | 24 | 25 | 24 | 28 |
| 4 | 21 | 21 | 1 | 9 | 5 | 22 | 3 | 38 |
| 8 | 21 | 19 | 1 | 4 | 2 | 15 | 2 | 28 |
| LSD 5% | Not significant | | 6 | 7 | 10 | 7 | 7 | 6 |

[a]Bedstraw 10 inches tall and birdsfoot trefoil 5 inches when treated.

differences for chemicals or rate-chemical interaction. Unsatisfactory bedstraw control resulted from the ½, 1, and 2 lb/A applications of all three materials. In early May most bedstraw plants given the 4 and 8 lb/A rates of all three materials seemed killed because there was no top growth, but in early July or later some regrowth of old plants was evident. This regrowth may be due to poor coverage in some cases since bedstraw was 10 inches tall and well matted at the time of application.

The amount of recovery of birdsfoot trefoil plants was more striking. Where significant differences in rate and interaction had been found in early May, none were found in July or later.

At the time of first cutting, June 6, 1957, there was a marked effect of rate of chemical on height of the birdsfoot trefoil. This height reduction, associated directly with rate of application, brought about a significant reduction of yield; however, by the time of second cutting, August 20, 1957, the effect of initial injury was not obvious. In fact, total yield increased with increased rate of application; but the increase was not all due to birdsfoot trefoil (Table 3). The botanical compositions of the second cutting show that the 4 and 8 lb/A rates completely prevented all bedstraw growth. Of more concern, however, was the fact that the percentage of broadleaf weeds increased as the rate of the amines increased.

*Fall application of esters.*

Fall application of propylene glycol butyl ether (PGBE), iso-octyl, and butoxyethanol esters of silvex gave results about equal to the amine salts when applied at corresponding rates (Table 4). As pre-

*Table 3.* Average dry weight yield (lb/A) of botanical components of the second cutting, August 20, 1957, following fall application of alkanolamine salts of 2-(2,4-DP), silvex, and 2-(MCPP) and of the propylene glycol butyl ether, iso-octyl, and butoxyethanol esters of silvex.

| Rate of herbicide lb/A | Lb/A of botanical components | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bedstraw | | Birdsfoot trefoil | | Grass | | Broadleaf weeds | |
| | A[a] | E[b] | A | E | A | E | A | E |
| 0 | 740 | 760 | 500 | 620 | 80 | 30 | 350 | 180 |
| ½ | 1180 | 420 | 250 | 920 | 30 | 80 | 220 | 250 |
| 1 | 980 | 70 | 390 | 950 | 50 | 180 | 360 | 570 |
| 2 | 140 | 18 | 920 | 890 | 210 | 180 | 780 | 720 |
| 4 | 0 | 0 | 550 | 460 | 240 | 180 | 1240 | 1180 |
| 8 | 0 | 0 | 260 | 130 | 180 | 561 | 1530 | 1470 |

[a]Amines—values based on 3 replications of each amine.
[b]Esters—values based on 2 replications of each ester.

dicted from the initial greenhouse tests, the silvex esters showed greater activity at low rates than did the amines on established plants. At 1 lb/A or higher, all silvex esters significantly reduced the stand of bedstraw. Also as noted before, some regrowth occurred at all rates where apparently 100 percent control had been obtained earlier. The esters gave better bedstraw control with less injury to birdsfoot trefoil than the amine salts, particularly at the 1 and 2 lb/A rates.

The effect of silvex ester treatments on yield the following year paralleled the results obtained with amine salts (Table 3). Figure 2

*Table 4.* Stands of bedstraw (B) and birdsfoot trefoil (T) as affected by application of silvex esters on November 16, 1956.[a] Each value based on 2 replications.

| Herbicide and rate, lb/A | Number of plants in 96 sq ft on | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Nov. 14, 1956 | | May 7, 1957 | | June 29, 1957 | | Sept. 17, 1957 | |
| | B | T | B | T | B | T | B | T |
| Propylene glycol butyl ether ester: | | | | | | | | |
| 0 | 31 | 31 | 27 | 38 | 40 | 55 | 48 | 35 |
| ½ | 28 | 32 | 4 | 32 | 19 | 64 | 26 | 32 |
| 1 | 29 | 28 | 0 | 28 | 3 | 48 | 14 | 37 |
| 2 | 30 | 30 | 0 | 28 | 2 | 66 | 5 | 40 |
| 4 | 34 | 34 | 0 | 23 | 4 | 50 | 5 | 37 |
| 8 | 29 | 30 | 0 | 1 | 1 | 7 | 2 | 10 |
| Iso-octyl ester | | | | | | | | |
| 0 | 37 | 32 | 35 | 31 | 61 | 47 | 62 | 34 |
| ½ | 37 | 30 | 15 | 24 | 37 | 61 | 40 | 35 |
| 1 | 30 | 27 | 5 | 28 | 20 | 59 | 30 | 35 |
| 2 | 39 | 25 | 0 | 23 | 2 | 57 | 2 | 34 |
| 4 | 40 | 22 | 0 | 8 | 0 | 36 | 1 | 29 |
| 8 | 49 | 23 | 0 | 5 | 0 | 6 | 2 | 15 |
| Butoxyethanol ester | | | | | | | | |
| 0 | 34 | 29 | 38 | 32 | 57 | 52 | 53 | 39 |
| ½ | 35 | 27 | 9 | 31 | 45 | 65 | 40 | 41 |
| 1 | 40 | 31 | 1 | 33 | 3 | 68 | 6 | 44 |
| 2 | 42 | 32 | 0 | 31 | 0 | 60 | 2 | 53 |
| 4 | 52 | 26 | 0 | 11 | 1 | 50 | 2 | 35 |
| 8 | 46 | 24 | 0 | 6 | 2 | 30 | 3 | 31 |
| LSD 5% | Not significant | | 7 | 9 | 12 | 16 | 11 | 11 |

[a]Bedstraw 10 inches tall and birdsfoot trefoil 6 inches when treated.

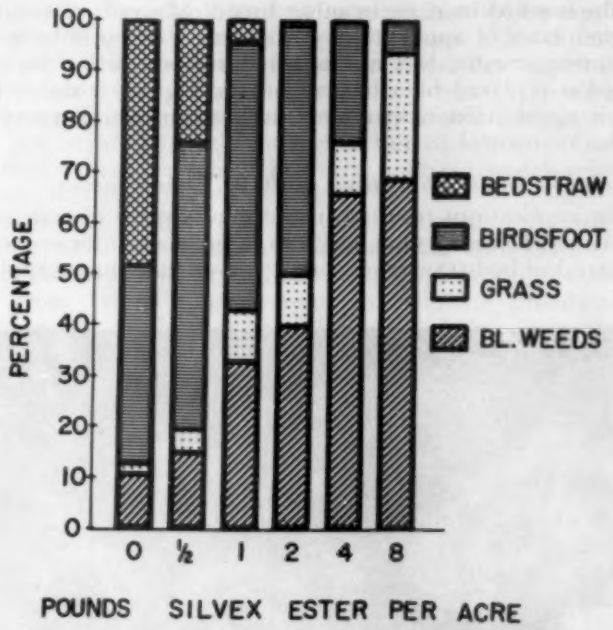



*Figure 2.* Average effects of the propylene glycol butyl ether, iso-octyl, and butoxyethanol esters of silvex applied on November 17, 1956, on the botanical composition of the second cutting as influenced by rate. Ithaca, New York, August 20, 1957. Each value based on 2 replications of each ester.

*Figure 3.* Effect of fall application of 2 and 4 lb/A of iso-octyl ester of silvex on bedstraw control in birdsfoot trefoil. Left: 4 lb/A almost completely removed bedstraw and allowed birdsfoot trefoil, grass and broadleaf weeds to take over. Right: 2 lb/A materially reduced bedstraw stand but occasional stunted bedstraw plant was present. Untreated plot at extreme left foreground has large bedstraw plants. Photographed June, 1957.

shows the marked increase in other broadleaf weeds, particularly at the higher rates of application. An overall spray of 4 or 8 lb/A of either amine or ester does not benefit birdsfoot trefoil, for one serious weed is replaced by a host of others. Figures 3 and 4 indicate what fall application of esters of silvex as an overall spray can do for bedstraw control.

*Spring and summer applications of PGBE ester of silvex.*

Spring applications resulted in the same degree of control as fall applications (Table 5). One and 2 lb/A gave a significant reduction in the stand of bedstraw from spring as well as summer applications

*Figure 4.* Effect of fall application of 8 lb/A of propylene glycol butyl ether ester of silvex on bedstraw control in birdsfoot trefoil. Complete removal of bedstraw plants on the right. The butoxyethanol and iso-octyl esters of silvex gave similar results. Photographed June, 1957.

*Table 5.* Stands of bedstraw (B) and birdsfoot trefoil (T) as affected by spring (May 17) and summer (July 6) applications of propylene glycol butyl ether ester of silvex, counted September 19, 1957. Each value based on 2 replications.

| Silvex rate lb/A | Number of plants in 96 sq ft after treatment on | | | |
|---|---|---|---|---|
| | May 17, 1957[a] | | July 6, 1957[b] | |
| | B | T | B | T |
| 0 | 42 | 32 | 31 | 33 |
| ½ | 39 | 31 | 25 | 28 |
| 1 | 19 | 39 | 5 | 32 |
| 2 | 5 | 31 | 2 | 12 |
| 3 | 0 | 26 | 1 | 4 |
| 4 | 4 | 28 | 0 | 4 |
| LSD 5% | 7 | | 7 | |

[a]Bedstraw 11 inches tall and birdsfoot trefoil 7 inches when treated.
[b]Bedstraw 6 inches tall and birdsfoot trefoil 4 inches when treated.

(approximately 2 weeks after first cutting) but spring application gave much less initial birdsfoot trefoil injury. The difference in birdsfoot trefoil injury is due in part to the difference in recovery time when observed. Because of inclement weather, spring treatments were applied a month later than planned. The data suggest possible less injury to birdsfoot trefoil but equal bedstraw control at an earlier date of treatment; however, further research is necessary to evaluate this possibility.

No forage was available for harvest from plots receiving spring application until late August. The botanical composition of the harvest is shown in Figure 5. The spring application of silvex ester differed from the fall applications in reducing broadleaf weed encroachment at the high rates and allowing more desirable forage grasses to predominate. The lack of birdsfoot trefoil in the sward was due to slower recovery from initial stunting.

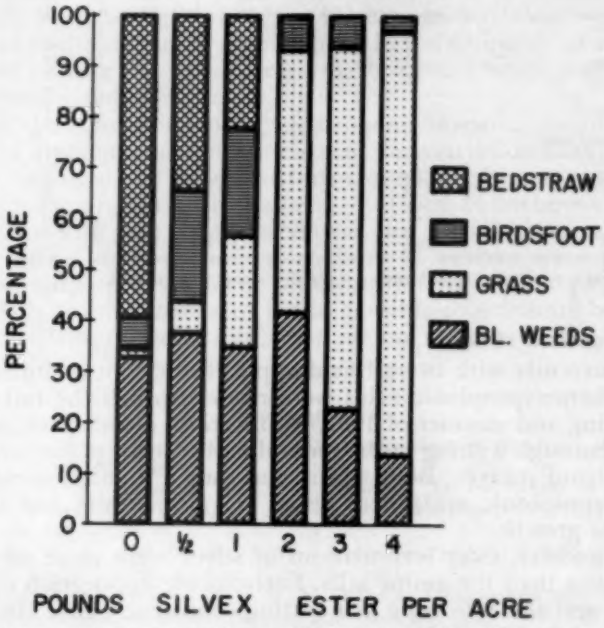



*Figure 5.* Effect of spring application (May 17) of the propylene glycol butyl ether ester of silvex on the botanical composition of the second cutting as influenced by rate. Ithaca, New York, August 20, 1957. Each value based on 3 replications. The total yields ranged from 2000 to 2330 lb/A.

*Summer applications of silvex esters.*

Stand counts from additional plots receiving summer application of silvex esters, 2 weeks after first cutting, are shown in Table 6. As in Table 5, significant bedstraw control was obtained, but more

initial injury to birdsfoot trefoil occurred. No forage yield was obtained when application was made in summer. By early spring of 1958 the birdsfoot trefoil plants had completely recovered except on plots treated with 5 lb/A. Some regrowth of bedstraw had also occurred, as in other field trials.

*Table 6.* Stands of bedstraw (B) and birdsfoot trefoil (T) as affected by applications of silvex esters July 6, 1957.* Each value based on 4 replications.

| Herbicide and rate, lb/A | Number of plants in 96 sq ft on | | | |
|---|---|---|---|---|
| | June 27, 1957 | | Sept. 20, 1957 | |
| | B | T | B | T |
| Propylene glycol butyl ether ester | | | | |
| 0 | 47 | 48 | 57 | 38 |
| 1 | 46 | 37 | 21 | 37 |
| 2 | 46 | 45 | 5 | 18 |
| 3 | 46 | 44 | 5 | 5 |
| 4 | 48 | 41 | 2 | 3 |
| 5 | 45 | 45 | 1 | 3 |
| Iso-octyl ester | | | | |
| 0 | 45 | 33 | 54 | 30 |
| 1 | 41 | 35 | 22 | 24 |
| 2 | 36 | 38 | 7 | 17 |
| 3 | 45 | 35 | 5 | 4 |
| 4 | 39 | 33 | 2 | 2 |
| 5 | 40 | 32 | 1 | 2 |
| Butoxyethanol ester | | | | |
| 0 | 36 | 40 | 41 | 33 |
| 1 | 38 | 37 | 7 | 31 |
| 2 | 35 | 44 | 1 | 14 |
| 3 | 33 | 37 | 0 | 4 |
| 4 | 41 | 36 | 0 | 2 |
| 5 | 28 | 35 | 0 | 1 |

*Bedstraw 6–8 inches tall and birdsfoot trefoil 3–5 inches when treated.

*Spot-treatment studies.*

Concurrently with overall field applications, spot treatments with alpha-phenoxypropionic acids were made through the fall of 1956 and spring and summer of 1957. Applications of sufficient gallonage to get thorough wetting of the individual bedstraw plants were made with a hand sprayer. Both amine and ester formulations of alpha-phenoxypropionic acids were tested at various rates and stages of bedstraw growth.

As elsewhere, ester formulations of silvex were more effective at lower rates than the amine salts. Early spring application of 3 lb/A of ester and also following first cutting consistently gave 100 percent control of bedstraw. No regrowth was noted on any spot-treated plant in the spring of 1958. All excavated roots of plants designated killed were found to be dry and brittle and considerable portions of the root system had disintegrated. Although bedstraw control was obtained at the pre-bloom, bloom and seed-set stages of growth by spot treatment, 7 lb/A was needed to get complete eradication.

## SUMMARY AND CONCLUSIONS

Chloro-substituted alpha-phenoxypropionic acids, 2-(2,4-dichlorophenoxy)propionic acid [2-2,4-DP)], 2-(2,4,5-trichlorophenoxy)-

propionic acid (silvex) and 2–(2–methyl–4–chlorophenoxy)propionic acid [2–(MCPP)], were effective for the control of bedstraw *(Galium mollugo)* and showed some degree of selectivity in birdsfoot trefoil at low rates. The degree of control obtained was a function of rate of herbicide used and stage of growth of bedstraw at time of application. Superior control was obtained by spraying vigorously growing bedstraw plants in the early vegetative stage of growth. Effective rates depended upon formulation used, with 2 lb/A of silvex esters being equivalent in activity to 4 lb/A of 2–(2,4–DP), silvex and 2–(MCPP) alkanolamine salts. No significant difference among the amine salts tested or among the esters of silvex was found.

Birdsfoot trefoil treated with alpha-phenoxypropionic acids even at low rates showed marked temporary injury. The total forage yield from first harvest after an overall application was consistently reduced regardless of time of application.

Fall applications of ester or amine formulations of alpha-phenoxypropionic acids brought about an increase in broadleaf weeds proportional to the rate used. Applications in the spring or on regrowth after first cutting did not increase the broadleaf weeds and at high rates actually reduced them.

Under the conditions of the experiments reported, overall applications of alpha-phenoxypropionic acid derivatives on heavy infestations of bedstraw—30 to 40 bedstraw clumps per 96-square-foot area with each clump having a diameter of 15 to 24 inches—complete eradication with one application was not obtained regardless of rate. Bedstraw stand reductions of 90 to 95 percent were possible. However, with spot-treatment follow-up on individual plants that survived the initial treatment it was possible to eradicate bedstraw. In light bedstraw infestations, spot treatment control was effective with 3 lb/A of a silvex ester.

## LITERATURE CITED


1. ABERG, E. Weed control research and development in Sweden. Brit. WCC Proc. 3:141–162. 1956.
2. BYRNES, W. R., BRAMBLE, W. C., and WORLEY, D. P. A test of 2,4,5–TP, 2,4,5–T and ATA on mixed oaks and associated species. NEWCC Proc. 11:118–195. 1957.
3. COULTER, L. L., and GIBSON, J. W. A progress report of field experience with silvex. NCWCC Proc 11:90–91. 1954.
4. DARROW, R. A., and MCCULLY, W. Y. Effects of single and repeated aerial applications of herbicides on post and blackjack oak. NCWCC Res. Rpt. 11:124–125. 1954.
5. ELWELL, H. M. New herbicide controlled oak brush and resulted in increased native grass production. Weeds 2:302–303. 1953.
6. ———, ELDER, W. C., KLINGMAN, D. L., and LARSON, R. E. Aerial applications of herbicides on oak in Oklahoma. NCWCC Proc. 11:91–95. 1954.
7. FISHER, C. E., BEHRENS, R., and WATSON, J. Relative tolerance of cotton to some growth regulator herbicides used for brush control. SWC Proc. 7:268–274. 1954.
8. FULTS, J. L., and PAYNE, M. Y. A biometric evaluation of the growth-regulating and herbicidal properties of some organic compounds. J. Amer. Soc. Agron. 39:667–681. 1947.
9. GIBSON, J. W. Silvex—a new herbicide for brush control in the South SWC Proc. 8:255–259. 1955.

10. HITCHCOCK, A. E., and ZIMMERMAN, P. W. Root-inducing activity of phenoxy compounds in relation to their structure. Contrib. Boyce Thomp. Inst. 12:497–507. 1942.
11. ——— and ———. Comparative root-inducing activity of phenoxyacids. Am. Soc. Hort. Sci. Proc. 45:187–189. 1944.
12. ——— and ———. Methods of rating the root-inducing activity of phenoxy acids and other growth substances. Contrib. Boyce Thomp. Inst. 14:21–38. 1945.
13. KORSMO, E. Anatomy of Weeds. Grondahl and Sons, Oslo. 1954.
14. LEAFE, E. L. A new development in selective weed control. Part II. Effect on cereal development. Brit. WCC Proc. 3:633–642. 1956.
15. LUSH, G. B. A new development in selective weed control. Part I. Introduction and weed control data. Brit. WCC Proc. 3:625–632. 1956.
16. SELLECK, Y. W., and COUPLAND, R. T. Relative effect of 2-(2,4,5-TP) in comparison with 2,4-D on annual weeds. Canad. Nat'l. Weed Comm. West. Sec. Res. Rpt. p. 76. 1956.
17. SHAW, W. C., and GENTNER, W. A. The selective herbicidal properties of several variously substituted phenoxyalkylcarboxylic acids. Weeds 5:75–92. 1957.
18. SILKER, T H., and DARROW, R. A. Aerial applications of 2,4,5-T and silvex for hardwood control and increased forage production in scrub-hardwood-pine stands in East Texas. SWC Proc. 9:130–133. 1956.
19. STEENIS, J. H., ADAMS, D., and WILSON, K. A. Investigations on alligator weed control. Weed Soc. Am. Abst. 2:59. 1958.
20. TERRY, C. W. Experimental mechanical equipment for application of weed control chemicals. NEWCC Proc. 6:3–5. 1952.
21. THOMPSON, H. E., SWANSON, C. P., and NORMAN, A. G. New growth regulating compounds. I. Summary of growth inhibitory activities of some organic compounds as determined by three tests. Bot. Gaz. 107:476–507. 1946.
22. WILTSE, M. G., DOLTON, R. L., FERGUSON, H. C., and ROSSMAN, W. R. Comparisons of commercial herbicides for brush control on power line rights-of-way. NEWCC Proc. 12:201–211. 1958.
23. YOUNGER, R. R. Preliminary studies using Kuron as an aquatic herbicide. NEWCC Proc. 12:332–337. 1958.

# Chemistry of Some Amino Acid Derivatives of Phenoxyalkylbutyric Acids

CHARLES F. KREWSON, EDWARD J. SAGGESE and THOMAS F. DRAKE[1]

## INTRODUCTION

THIS paper reports on the synthesis and properties of 38 new herbicides, amino acid derivatives of 4–(2,4–dichlorophenoxy)– and 4–(2–methyl–4–chlorophenoxy)butyric acids. The biological evaluation of the compounds as selective herbicides is being conducted by other investigators and will be published later.

In the past 18 years major advances have been made in the regulation of plant growth by use of synthetic organic compounds. Many of these new synthetics have reached commercial production and are widely utilized as herbicides. The most prominent among these have been the variously substituted phenoxyalkylcarboxylic acids. The literature abounds with reports on their structural configuration in relation to mode of action, growth-regulating properties and selective herbicidal properties. These researchers were stimulated by the early work on 2,4–dichlorophenoxyacetic acid and other related compounds triggered by such preparative contributions as Pokorny's (7) in 1941. Shaw and Gentner (9) in their paper on the selective herbicidal properties of substituted phenoxyalkylcarboxylic acids have briefly reviewed the literature on some of the most significant contributions concerning the biological activity of these acids.

Preliminary investigations [2,3] have shown that the chemical attachment of an amino acid through amide linkage to variously substituted phenoxycarboxylic acids affects the selective herbicidal properties of the latter. The effect seems to depend upon the type of amino acid and its optical configuration. The optimum effect observed so far has been with an amino acid phenoxy–α–propionic acid series.[4] Preliminary screening tests[5] (3, 4, 5) designed to measure growth-regulating activity of these compounds have been in close agreement with herbicidal evaluation data.[4] Activity tests have shown, for instance, a wide difference in the behavior pattern of compounds made from *D-*, *L-* and *DL-* optical forms of amino acids. This difference was greater in the α–propionic acid[4] (3) than in the

[1]Chemists, Eastern Regional Research Laboratory, Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Dept. of Agriculture, Phila. 18, Pa. Present address: T. F. Drake, Courtaulds, Inc., Mobile, Alabama.

[2]Gentner, W. A., and Shaw, W. C. An evaluation of several chemicals for their herbicidal properties—1957 field results. USDA Progress Report CR-25-58, ARS, Plant Industry Station, Beltsville, Maryland, January 1958, 59 p.

[3]Gentner, W. A., and Shaw, W. C. An evaluation of several chemicals for their herbicidal properties—1958 field results. USDA Progress Report CR-6-59, ARS, Plant Industry Station, Beltsville, Maryland, January 1959, 68 p.

[4]Shaw, W. C., and Gentner, W. A. Unpublished data.

[5]Krewson, C. F., Carmichael, J. F., Drake, T. F., Smale, B. C., and Mitchell, J. W. Growth Regulators. Synthesis and preliminary evaluations of amino acid derivatives of *DL*–2–(2,4,5–trichlorophenoxy)propionic acid. J. Agr. & Food Chem. In press.

acetic acid[4] (4, 5) series of phenoxy compounds tested. In most cases *D*-amino acid derivatives possessed little or no activity and *L*- and *DL*- derivatives possessed from a low to high order of activity compared with the parent acid depending upon the plant tested and the amino acid utilized.

## OBJECTIVE OF THESE INVESTIGATIONS

The purpose of the studies reported herein is two-fold: (1) to create new and useful compounds from naturally occurring source materials of agricultural origin such as amino acids; and (2) through cooperative studies, to expand knowledge of the selective herbicidal properties[2,3] of the phenoxycarboxylic acids by extending the preparation of amino acid derivatives[5] (3, 4, 5, 6) to include the most important of the variously substituted phenoxybutyric acids, 4–(2,4–DB) and 4–(MCPB). This latter objective is to be accomplished by investigating the relation of structural configuration to specificity, mode of action, and herbicidal effectiveness of the compounds, for the control of weeds in a number of important crops. In this connection, Wain (10) has stated: "Reviewing the evidence at present available, it would seem that the principle underlying the use of γ–(2–methyl–4–chlorophenoxy)butyric acid, γ–(2,4–dichlorophenoxy)butyric acid, and other aryloxybutyric, caproic, and octanoic acids represents a new advance in the field of selective weed control, a development which well illustrates the value of fundamental investigations in furthering the progress of applied research."

## SYNTHESIS OF AMINO ACID DERIVATIVES OF 4–(2,4–DB) AND 4–(MCPB)

For the preparation of amino acid derivatives of these phenoxy compounds procedures similar to those previously described (3, 4, 5, 6, 11) were employed. The amino acids and the two aryloxybutyric acids used in this work were the best obtainable through commercial sources.[6]

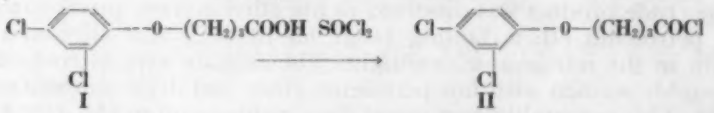
For amide coupling with the amino acids the 4–(2,4–DB) and 4–(MCPB) were first converted into their acyl chlorides (2, 5). The following description illustrates the procedure used to prepare both acyl chlorides.

*4–(2,4–Dichlorophenoxy)butyryl chloride.* This intermediate was prepared in 89.1% yield by the reaction of 249.1 grams (1.0 *M*) of 4–(2,4–DB) (I) with 158.0 grams (1.33 *M*) of thionyl chloride. The mixture was refluxed on a steam-bath for 4 hours, allowed to stand overnight protected from air moisture and then distilled under reduced pressure. A main fraction of 239.0 grams distilling at 136–140° C. under 0.2 mm pressure with a constant index of refraction, $n^{25}_D$, 1.5465 was collected following the discard of a small forerun

[6]Supplied through the countesy of Amchem Products, Inc., Ambler, Pennsylvania, and May and Baker, Ltd., Daggenham, England. Mention of company or product does not constitute endorsement by the Department over others not named.

fraction. The product (II) consisted of a colorless, supercooled liquid which crystallized upon refrigeration. The melting range of this material was 17.0–22.0° C. (uncorr.).

| Analyses for $C_{10}H_9Cl_3O_2$: | Calc'd. (%) | Found (%) |
|---|---|---|
| Carbon | 44.89 | 44.93 |
| Hydrogen | 3.39 | 3.38 |
| Chlorine | 39.76 | 39.43 |



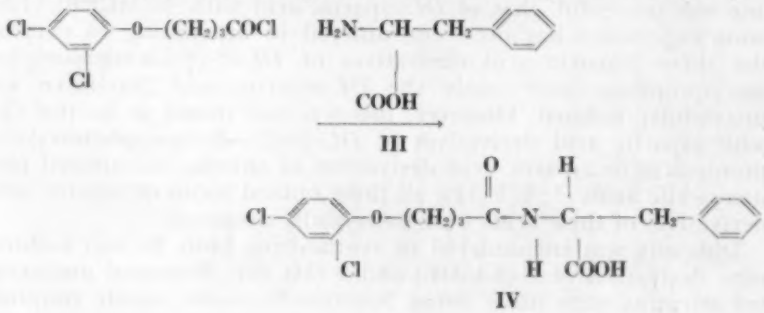

I II

*4–(2–Methyl–4–chlorophenoxy)butyryl chloride.* This compound was prepared in 73.5% yield using the same techniques as described above for the 4–(2,4–DB) chloride. Its boiling range was 115–122° C. at 0.2 mm with a constant index of refraction, $n^{25}_D$, 1.5340. The product also consisted of a colorless, supercooled liquid which crystallized when stored in the refrigerator. It melted at 5.0–9.0° C.

| Analyses for $C_{11}H_{12}Cl_2O_2$: | Calc'd. (%) | Found (%) |
|---|---|---|
| Carbon | 53.46 | 53.45 |
| Hydrogen | 4.90 | 5.19 |
| Chlorine | 28.70 | 28.62 |

*N–[4–(2,4–Dichlorophenoxy)butyryl]–DL–phenylalanine.* The following details are included to illustrate the general procedure used to prepare the amino acid derivatives of both 4–(2,4–DB) and 4–(MCPB): To 5.0 grams (0.03 *M*) of *DL*-phenylalanine (III) dissolved in 90 ml. of chilled 1 *N* sodium hydroxide solution was added dropwise with mechanical stirring 25 ml. of a cold (5° C.) benzene solution containing 8.0 grams of 4–(2,4–dichlorophenoxy)butyryl chloride. The addition of the benzene solution required 15–20 minutes. A temperature of 5° C. was maintained throughout the addition. Following the addition of all the benzene solution the reaction mixture, with constant stirring, was allowed to warm up to room temperature; stirring was continued for three hours.

The alkaline reaction mixture was extracted three times, once with about 50 ml. and twice with 25 ml. of diethyl ether. The combined ether extracts were washed once with about 25 ml. of distilled water, the latter being returned to the original alkaline aque-




IV

ous solution. This solution was then acidified with 1 *N* hydrochloric acid using Congo Red test paper following which it was placed in the refrigerator for an overnight period. The product (IV) was filtered off, washed with water to remove excess acid and dried to constant weight in a vacuum desiccator. The weight of the crude product was 11.0 grams (92.2% yield), m.p. 121–130° C. (Kofler micro melting point apparatus).

The crude product was dissolved in hot ethyl acetate, precipitated with petroleum ether (boiling range 63–70° C.), and allowed to remain in the refrigerator overnight. The crystals were filtered off, thoroughly washed with hot petroleum ether and dried to constant weight. This recrystallization raised the melting point to 135–139° C. The product was again recrystallized from the same solvent system. The melting point of the refined produce was 140–141° C.; it weighed 9.36 grams (78.8% yield).

| Analyses for $C_{19}H_{19}Cl_2NO_4$: | Calc'd. (%) | Found (%) |
|---|---|---|
| Chlorine | 17.89 | 17.68 |
| Nitrogen | 3.53 | 3.53 |

See Tables 1 and 2 for data on this and other amino acid derivatives prepared.

## Discussion of Chemistry

In the preparation of most amino acid derivatives of 4–(2,4–DB) and 4–(MCPB) the crude products separated either as crystalline white solids or colorless oils which often crystallized on prolonged standing at about 5° C. Occasionally these oils did not crystallize at low temperatures. After thorough washing with water they were submitted to continuous evacuation which usually produced amorphous solids. These solids were then recrystallized in the manner previously described.

Repeated recrystallization of some derivatives was necessary to obtain satisfactory chemical and optical purity. The solvent combinations required have been indicated by footnotes in Tables 1 and 2. In these refinements of crude amino acid derivatives no attempts were made to improve yields by working up mother liquors from the recrystallizations.

Although one or more attempts were made to prepare *D-*, *L-*, and *DL-* aspartic acid derivatives of 4–(2,4–DB) and 4–(MCPB) only one was successful, that of *DL*-aspartic acid with 4–(MCPB). This same experience has been encountered in attempting to prepare the three aspartic acid derivatives of *DL*–2–(2,4,5–trichlorophenoxy)propionic acid[5]; only the *DL*-aspartic acid derivative was successfully isolated. However, this was not found to be the case with aspartic acid derivatives of *DL*–2–(2,4–dichlorophenoxy)propionic acid or aspartic acid derivatives of chlorine-substituted phenoxyacetic acids (3, 4, 5, 11); all three optical forms of aspartic acid derivatives of these acids were successfully prepared.

Difficulty was encountered in synthesizing both *D-* and *L*-threonine derivatives of 4–(2,4–DB) and 4–(MCPB). Repeated unsuccessful attempts were made using Schotten-Baumann amide coupling

*Table 1.* Yields, physical properties and analyses of amino acid derivatives of 4-(2,4-dichlorophenoxy) butyric acid.

| N-[4-(2,4-Dichlorophenoxy) butyryl]- | M.P., °C[a] (Corr.) | Yield per cent | | Formula | Analyses[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cl per cent | | N. per cent | | Optical Rotation | |
| | | Crude | Refined | | Calcd. | Found | Calcd. | Found | $[\alpha]_D^{25}$ | C (g./100 ml.) in pyridine |
| *L*-alanine | 98.0–100.0[c] | 76.4 | 56.2 | $C_{13}H_{15}Cl_2NO_5$ | 22.14 | 21.85 | 4.37 | 4.35 | − 7.83 ±0.4 | 2.00 |
| *D*-alanine | 96.0– 98.0 | 51.2 | 41.8 | | 22.14 | 21.70 | 4.37 | 4.41 | + 8.36 ±0.4 | 2.00 |
| *DL*-alanine | 116.0–119.0 | 48.6 | 40.1 | | 22.14 | 21.80 | 4.37 | 4.40 | | |
| *L*-leucine | 82.0– 84.0 | 70.1 | 48.8 | $C_{16}H_{21}Cl_2NO_4$ | 19.57 | 19.36 | 3.87 | 3.85 | −14.40 ±0.4 | 2.00 |
| *D*-leucine | 71.0– 75.0[d] | 81.0 | 34.9 | | 19.57 | 19.52 | 3.87 | 3.84 | +12.81 ±0.6 | 2.00 |
| *DL*-leucine | 103.0–104.0 | 84.7 | 63.6 | | 19.57 | 19.09 | 3.87 | 3.92 | | |
| *L*-methionine | 55.0– 60.0 | 77.2 | 17.8 | $C_{15}H_{19}Cl_2NO_4S$ | 18.65 | 18.40 | 3.68 | 3.70 | − 3.54 ±0.5 | 2.00 |
| *D*-methionine[e] | 123.0–125.0[f] | 92.6 | 15.0 | | 18.65 | 18.98 | 3.68 | 3.65 | − 0.1 ±0.6 | 2.05 |
| *DL*-methionine | 122.0–123.0 | 85.0 | 66.3 | | 18.65 | 18.48 | 3.68 | 3.68 | | |
| *L*-phenylalanine | 132.5–134.0[g] | 87.5 | 71.3 | $C_{19}H_{19}Cl_2NO_4$ | 17.89 | 17.75 | 3.53 | 3.61 | +16.23 ±0.6 | 2.05 |
| *D*-phenylalanine | 131.0–132.0 | 70.9 | 60.6 | | 17.89 | 17.79 | 3.53 | 3.65 | −18.00 ±3.0 | 0.65 |
| *DL*-phenylalanine | 140.0–141.0 | 92.2 | 78.8 | | 17.89 | 17.68 | 3.53 | 3.53 | | |
| *L*-threonine[e] | 99.0–101.0[h] | 53.0 | 10.6 | $C_{14}H_{17}Cl_2NO_5$ | 20.25 | 20.43 | 4.00 | 3.95 | + 2.48 ±0.8 | 0.93 |
| *D*-threonine[e] | 89.0– 95.0 | — | 4.3 | | 20.25 | 20.56 | 4.00 | 3.86 | − 1.63 ±0.4 | 2.00 |
| *DL*-threonine[e] | 168.0–169.0[g] | 57.1 | 30.9 | | 20.25 | 20.42 | 4.00 | 4.09 | | |
| *L*-tryptophane | 185.0–186.5 | 73.5 | 71.3 | $C_{21}H_{20}Cl_2N_2O_4$ | 15.95 | 15.85 | 6.47 | 6.38 | +20.67 ±0.5 | 2.00 |
| *D*-tryptophane | 187.0–189.0[i] | 88.0 | 74.3 | | 15.95 | 16.09 | 6.47 | 6.45 | −21.14 ±0.5 | 2.00 |
| *DL*-tryptophane | 168.0–169.0[e] | 85.0 | 61.9 | | 15.95 | 15.97 | 6.47 | 6.42 | | |
| N,N′-bis-[4-(2,4-Dichlorophenoxy) butyryl]—*L*-cystine | 154.0–155.5[e,j] | 43.4 | 27.8 | $C_{26}H_{28}Cl_4N_2O_6S_2$ | 20.19 | 19.73 | 3.99 | 3.98 | 64.68 ±0.6 | 2.05 |

[a] Recrystallized one or more times from ethyl acetate–petroleum ether unless otherwise indicated.
[b] Analyses by J. S. Ard and E. L. Nutter.
[c] And recrystallized from hot ethanol-water.
[d] And purified through preparation of its cyclohexylamine salt.
[e] Prepared by J. F. Carmichael.
[f] Recrystallized from hot ethanol–n-hexane, hot dilute acetic acid, acetone–water, dioxane–water and dichloroethane–n-hexane.
[g] Recrystallized from hot ethanol–water only.
[h] And from hot dilute acetic acid.
[i] Recrystallized from hot methanol–water (norit treated) and hot ethanol–water.
[j] Also extracted 12 hours with petroleum ether in a Soxhlet.

*Table 2.* Yields, physical properties and analyses of amino acid derivatives of 4-(2-methyl-4-chlorophenoxy) butyric acid.

| N-[4-(2-Methyl-4-chlorophenoxy) butyrl]— | M.P., °C.[a] (Corr.) | Yield, per cent | | Formula | Analyses[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cl per cent | | N per cent | | Optical Rotation | |
| | | Crude | Refined | | Calcd. | Found | Calcd. | Found | $[\alpha]_D^{25}$ | C (g./100 ml.) in pyridine |
| *L*-alanine | 108.0-110.0[c] | 84.9 | 53.1 | $C_{14}H_{18}ClNO_4$ | 11.83 | 12.00 | 4.67 | 4.46 | − 4.84 ±0.4 | 2.00 |
| *D*-alanine | 113.0-115.0 | 76.8 | 49.0 | | 11.83 | 11.76 | 4.67 | 4.64 | + 5.16 ±0.4 | 2.00 |
| *DL*-alanine | 118.0-119.0 | 79.5 | 43.5 | | 11.83 | 11.85 | 4.67 | 4.68 | | |
| *DL*-aspartic acid | 148.0-151.0 | 44.3 | 22.4 | $C_{13}H_{15}ClNO_6$ | 10.31 | 10.20 | 4.07 | 4.14 | | |
| *L*-leucine | 71.0-73.0 | 71.7 | 41.1 | $C_{17}H_{24}ClNO_4$ | 10.37 | 10.35 | 4.10 | 4.10 | − 7.38 ±0.4 | 2.00 |
| *D*-leucine | 89.0-90.0 | 84.8 | 73.1 | | 10.37 | 10.40 | 4.10 | 4.11 | +11.15 ±0.4 | 2.00 |
| *DL*-leucine | 111.0-112.0 | 69.3 | 43.8 | | 10.37 | 10.53 | 4.10 | 4.12 | | |
| *L*-methionine | 70.0- 73.0 | 84.3 | 65.8 | $C_{16}H_{22}ClNO_4S$ | 9.85 | 10.04 | 3.89 | 3.81 | − 1.54 ±0.4 | 2.00 |
| *D*-methionine | 67.0- 70.0[d] | 77.1 | 26.3 | | 9.85 | 9.75 | 3.89 | 3.87 | + 0.72 ±0.5 | 2.00 |
| *DL*-methionine | 99.0-100.0 | 75.2 | 46.4 | | 9.85 | 10.07 | 3.89 | 3.86 | | |
| *L*-phenylalanine | 134.0-135.0 | 58.5 | 55.9 | $C_{20}H_{22}ClNO_4$ | 9.43 | 9.67 | 3.73 | 3.69 | +20.30 ±0.4 | 2.00 |
| *D*-phenylalanine | 130.0-132.0 | 90.4 | 81.0 | | 9.43 | 9.55 | 3.73 | 3.68 | − 23.03 ±0.4 | 2.00 |
| *DL*-phenylalanine | 135.0-137.0 | 98.4 | 90.4 | | 9.43 | 9.50 | 3.73 | 3.68 | | |
| *L*-threonine (−$H_2O$) | 158.0-159.0[e] | — | 4.5 | $C_{14}H_{18}ClNO_4$ | 11.37 | 11.29 | 4.49 | 4.51 | 0.00 ±0.4 | 2.00 |
| *D*-threonine (−$H_2O$) | 160.0-161.0[e] | | 9.0 | | 11.37 | 11.26 | 4.49 | 4.50 | 0.00 ±0.4 | 2.00 |
| *DL*-threonine | 170.0-172.0 | 83.0 | 52.2 | $C_{18}H_{20}ClNO_5$ | 10.75 | 10.78 | 4.24 | 4.23 | | |
| *L*-tryptophane | 187.0-189.0[f] | 94.6 | 65.8 | $C_{22}H_{23}ClN_2O_4$ | 8.50 | 8.47 | 6.72 | 6.73 | +21.65 ±0.5 | 2.00 |
| *D*-tryptophane | 190.5-192.0[f] | — | 78.2 | | 8.50 | 8.54 | 6.72 | 6.79 | − 22.13 ±0.5 | 2.01 |
| *DL*-tryptophane | 172.0-173.0[f] | 96.6 | 80.6 | | 8.50 | 8.52 | 6.72 | 6.78 | | |

[a]Recrystallized one or more times from ethyl acetate-petroleum ether unless otherwise stated.
[b]Analyses by J. S. Ard and E. L. Nutter.
[c]Preceded by recrystallization from ethanol-water.
[d]And purified through preparation of its cyclohexylamine salt.
[e]Preceded by recrystallization from chloroform-petroleum ether.
[f]From methanol-water only. Methanol solution of *L*-tryptophane derivative norit treated.

techniques described for IV above. Finally, by this method small amounts of the *D*- and *L*-threonine derivatives of 4–(2,4–DB) were obtained after failures with the Ronwin method (8), the Carter et al. method (1) and a number of variations on these procedures. It was first thought that the *L*-threonine derivative of 4–(2,4–DB) was a lactone due to the close check of an elemental chlorine analysis with the calculated value for a lactone. The compound therefore was supplied at this stage of purification for biological evaluation along with the other members of these two series. However, nitrogen analysis performed at a later date failed to confirm lactone formation. Further purification gave the desired product, giving the data presented in Table 1, which are for the highly purified product. Biological evaluations made on the impure compound will be interpreted in the light of the presence of a small amount of the phenoxy parent acid contaminant.

The preparation and identification of the *D*- and *L*-threonine derivatives of 4–(MCPB) will be the subject of another report since this chemistry became somewhat involved. The chlorine and nitrogen analyses data support the formation of the desired compounds but with one less molecule of water. This water was formed by the loss of the hydroxyl group of threonine and a hydrogen atom from its terminal methyl group resulting in the formation of a terminal double bond:

$$R{-}CHOH{-}CH_3 \xrightarrow{-H_2O} R{-}CH{=}CH_2.$$

Since the completion of these studies threonine derivatives of phenoxy acids in general have been found to possess moderate water solubility which may account for the low yields experienced when Schotten-Baumann procedures have been used.

## SUMMARY

1. Thirty-eight new amino acid derivatives, 19 of 4–(2,4–DB) and 19 of 4–(MCPB) have been synthesized and their properties studied.

2. Both 4–(2,4–DB) and 4–(MCPB) formed amides with the *D*-, *L*-, and *DL*- optical forms of alanine, leucine, methionine, phenylalanine, threonine, and tryptophane.

3. Unsuccessful attempts were made to prepare the optically active aspartic acid derivatives of both 4–(2,4–DB) and 4–(MCPB). *DL*-asparatic acid did form an amide with 4–(MCPB but not with 4–(2,-4–DB).

4. *D*- and *L*-Threonine formed unique compounds with 4–(MCPB) involving the terminal methyl group of threonine in the formation of a double bond.

5. Most of these amino acid derivatives of the phenoxybutyric acids were readily prepared and analyzed and possessed sharp melting points; hence they may be useful in the characterization of amino acids.

6. Biological evaluation of these compounds as selective herbicides is being conducted by other investigators and will be reported later.

Some of the compounds are also being evaluated as estrogens, fungicides, insecticides, and anticancer agents.

LITERATURE CITED

1. CARTER, H. E., HANDLER, P., and STEVENS, C. M. Azlactones. III. Acylation of amino acids in pyridine. Jour. Biol. Chem. 138:619–626. 1941.
2. FREED, V. H. Preparation and reactions of 2,4–dichlorophenoxyacetyl chloride. Jour. Amer. Chem. Soc. 68:2112. 1946.
3. KREWSON, C. F., DRAKE, T. F., MITCHELL, J. W., and PRESTON, W. H., JR. Plant growth regulators. Preliminary screening tests of amino acid derivatives of 2–(2',4'–dichlorophenoxy)propionic acid. J. Agr. & Food Chem. 4:690–693. 1956.
4. ———, ———, NEUFELD, C. H. H., FONTAINE, T. D., MITCHELL, J. W., and PRESTON, W. H., JR. Growth regulators. Amino acid derivatives of 4–chlorophenoxyacetic acid and their plant-regulating effects in preliminary screening tests. J. Agr. & Food Chem. 4:140–143. 1956.
5. ———, NEUFELD, C. H. H., DRAKE, T. F., FONTAINE, T. D., MITCHELL, J. W., and PRESTON, W. H., JR. Synthetic plant-growth modifiers. IV. 2–Methyl–4–chlorophenoxyacetyl derivatives of amino acids. Weeds 3:28–37. 1954.
6. ———, SAGGESE, E. J., CARMICHAEL, J. F., ARD, J. S., DRAKE, T. F., MITCHELL, J. W., and SMALE, B. C. Growth regulators. Synthesis and preliminary evaluations of amide, lactic acid, and terpenoid derivatives of substituted phenoxycarboxylic acids. J. Agr. & Food Chem. 7:118–122. 1959.
7. POKORNY, R. Some chlorophenoxyacetic acids. Jour. Amer. Chem. Soc. 63:1768. 1941.
8. RONWIN, E. Direct acetylation of $\alpha$–amino acids and of $\alpha$–hydroxy acid derivatives. Jour. Org. Chem. 18:127–132. 1953.
9. SHAW, W. C., and GENTNER, W. A. The selective herbicidal properties of several variously substituted phenoxyalkylcarboxylic acids. Weeds 5:75–92. 1957.
10. WAIN, R. L. Herbicidal selectivity through specific action of plants on compounds applied. J. Agr. & Food Chem. 3:128–130. 1955.
11. WOOD, J. W., and FONTAINE, T. D. Synthetic plant-growth regulators. III. 2,4–Dichlorophenoxyacetyl derivatives of amino acids. Jour. Org. Chem. 17:891–896. 1952.

# Leafy Spurge Control with Cultivation, Cropping and Chemicals[1]

LYLE A. DERSCHEID, KEITH E. WALLACE and RUSSEL L. NASH[2]

LEAFY spurge is a perennial weed that is found in almost every state north of the fortieth parallel and in the southern portions of most Canadian provinces. Heaviest infestations are found in Minnesota, the Dakotas and the Prairie Provinces.

Hanson and Rudd (10) conducted extensive life history studies in North Dakota. They adopted the name *Euphorbia virgata* Waldst. & Kit.; however, Stevens (12), also of North Dakota, used the name *Euphorbia esula L.* The two names apparently were used for the same species. Hanson and Rudd (10) described it as a long-lived perennial herb, somewhat woody at the base, containing milk sap. It grows to a height of 14 to 40 inches and propagates by means of seeds and roots. Near Fargo, average plant height was ½ inch April 5, 1⅕ inches April 19, 3½ inches April 23, and 12½ inches April 30. Flowers began to appear by the end of May. This rapid early growth gives the weed a great advantage over most crop plants.

"The most formidable part of the plant is the root...It is well developed. The large tap root begins to branch into a number of large, woody, brown-colored branches near the surface. The fine roots are numerous, especially near the surface and when suitable conditions occur in deeper soil. The maximum depth at which roots were found was at the water table at 8 feet. The maximum lateral spread was 3½ feet" (10). This description is very similar to the description of the root system of field bindweed *(Convolvulus arvensis* L.) given by Frazier (9). The main differences are that the leafy spurge root is more woody and less extensive in a clay soil than the root of a non-competing bindweed plant growing in a sandy loam soil. Pieces of leafy spurge roots as small as one-half inch long and one-eighth inch in diameter produced new shoots which grew rapidly (10).

The fruit is a 3-chambered capsule, explosively dehiscent, usually along the line of union of the carpels. Normally each carpel contains one seed. Nearly 50 percent of the fruits produce one mature seed, about 35 percent produce two, and 15 to 20 percent produce three. In the vicinity of Fargo, the fruits begin to ripen about July 10 and continue until September. Upon maturity the seeds are forcibly discharged up to a distance of at least 13 feet. In one test, they were uniformly distributed in an area extending from 1 to 13 feet from the parent plant (10).

Thousands of acres of farmland are infested with leafy spurge.

[1]Approved for publication by the Director of the South Dakota Agricultural Experiment Station as Journal Series No. 429.

[2]Agronomist, South Dakota Agricultural Experiment Station; Extension Weed Specialist, South Dakota Extension Service (formerly Graduate Assistant); and Chief, Division of Seeds and Weeds, Nebraska Dept. of Agriculture (formerly Graduate Assistant at South Dakota State College) respectively.

Since it is not economically possible to put the land out of production while the leafy spurge is being eliminated, the objectives of the study reported in this paper were to determine methods of eliminating the weed in large areas while crops adapted to South Dakota were being produced and to determine methods of eliminating small infestations with chemicals.

Very few data could be found in the literature to serve as a guide when planning the study. However, life history studies (9, 10), root reserve studies (1, 3, 4, 8), and methods of control studies[3] (2, 3, 11, 13) indicated that leafy spurge and field bindweed were similar in growth habits, and that some of the methods for eliminating field bindweed were effective for the control of leafy spurge.

When bindweed roots were cut 4 inches below the soil surface every 14 days, root reserves were reduced (8). A duckfoot cultivator proved to be an effective implement for cutting the shoots in the field (11, 13), and it was desirable to start operations early in the spring to take advantage of the decline in root reserves during the winter (4). The 14-day interval between cultivations sometimes could be lengthened to 3 weeks, especially during the late summer when plants became dormant (13). In other work, the best interval was 2 weeks for bindweed, 3 weeks for Russian knapweed *Centaurea repens* L., and 4 weeks for hoary cress *(Cardaria draba* (L.) Desv.) and dogbane *(Apocynum cannabinum* L.) (14). Complete elimination of these weeds was obtained in 1 to 2.5 years. To secure similar results with leafy spurge, it was necessary to cultivate semi-weekly for 2 years when a spring-tooth harrow was used (2).

Early spring cultivation, followed by a close-seeded crop of forage sorghum, soybeans, or sudangrass harvested for forage, followed by fall cultivation, reduced bindweed stands and resulted in complete elimination when continued for 3 years (3, 11, 13). Similar results were obtained with leafy spurge (2). Buckwheat was an equally effective crop on quackgrass.

Alfalfa or alfalfa-perennial grass mixtures were sufficiently competitive to reduce stands of bindweed that had been weakened by a short season of intensive cultivation (3, 11). Perennial grasses prevented bindweed from spreading (13), but were less effective for reducing stands than alfalfa or alfalfa-grass mixtures (11). However, bindweed stands were reduced by spraying bromegrass with 2,4–D. Alfalfa was less effective for controlling leafy spurge (2).

Two or three crops of winter wheat or rye alternated with intensive cultivation between crops gave elimination of bindweed (3, 11, 13), and spring sown grains were equally effective. However, spring sown grains or corn could not compete effectively with leafy spurge (2). Spraying spring sown grains with 2,4–D could be used to replace cultivation between crops for the elimination of bindweed, but elimination was obtained in less time when spraying and cultivating were both utilized.

[3]Stahler, L. M., and Derscheid, Lyle A. Unpublished data from South Dakota Bindweed Research Farm, 1946–1950. These data support most of the statements made in this section on control of bindweed.

Numerous experiments conducted by the authors indicated that 2,4–D was equal to or superior to 2,4,5–T, MCPA, and several related chemicals for control of leafy spurge. Results indicated that the ester forms of 2,4–D were more readily absorbed than the amine forms. Leafy spurge reacted to less than one-fourth pound acid equivalent per acre. However, the stand was not materially reduced by 2 or 3 treatments in 1 year with much higher rates. Although the weed was easily affected by the chemical, it was quite resistant. It appeared that the weed could be weakened with 2,4–D so that a crop could compete more effectively with it or that cultivation could kill it more readily.

These results indicated that the objectives of this study could be attained with the proper combination of crops, cultivation, and chemicals. If the area were cultivated when not occupied by a crop and if the weed were selectively sprayed in a crop tolerant to the chemical, it appeared that several combinations might eliminate the weed in a few years.

## EXPERIMENTAL PROCEDURE AND RESULTS

Screening trials in which rates, dates, formulations, and chemicals were compared had been conducted during 1948–50. It became apparent that the chemicals available were not practical for elimination of large infestations of leafy spurge. Consequently 30 acres of land heavily infested with leafy spurge were leased during 1950 to study methods of eliminating this weed. The land was a part of the Pir Nilsson estate located 18 miles northeast of Clear Lake in Deuel County, South Dakota, where annual rainfall is normally about 22 inches.

Approximately one-third of the area was divided into plots in 1950, a second third was divided in 1951, and the remainder in 1952. Four general types of experiments were conducted: (1) 3-year trials involving the use of annual crops, cultivation, and 2,4–D; (2) 3-year trials involving the use of perennial crops, cultivation, and 2,4–D; (3) comparisons of soil sterilants applied at several rates and dates for eliminating small patches; and (4) 1-year tests in which new chemicals were screened for possible use on large infestations. Soil sterilant treatments were made on plots 9 by 15 feet, but all other plots were 1 rod by 3 or 5 rods. The soil had a loam texture.

### *Annual crops, cultivation, and 2,4–D.*

A 3-year experiment involving the use of annual crops (winter rye, oats, sudangrass, and buckwheat), intensive cultivation, and 2,4–D was initiated during the fall of 1950. Weed counts were made on 4 one-square-yard areas of each plot during the middle of May each year. The final counts were made in May, 1954. Identical 3-year experiments were initiated during the falls of 1951 and 1952, and they were completed during May, 1955 and 1956. Each experiment included the same 33 treatment combinations. Each treatment was repeated once in a randomized block design. The treatments and

the percentage of leafy spurge killed in the three experiments are given in Table 1.

*Table 1.* The mean percentages of leafy spurge eliminated by the use of annual crops, cultivation and 2,4–D (means for 3 experiments).

| First fall treatment | Second year | | Third year | | Fourth year | |
|---|---|---|---|---|---|---|
| | Treatment[a] | Per cent kill | Treatment[a] | Per cent kill | Treatment[a] | Per cent kill |
| 1. Plow | Cult. 2-wks. | 96 | Cult. 2-wks. | 100 | ——— | — |
| 2. Plow | Cult. 3-wks. | 92 | Cult. 3-wks. | 100 | ——— | — |
| 3. Rye | Cult., rye | 10 | Cult., buck. | 60 | Cult., buck. | 78 |
| 4. Rye | Cult., rye | 10 | Cult., sudan | 70 | Cult., sudan | 88 |
| 5. Rye | Cult., rye | 10 | Cult., rye | 22 | Cult., rye | 52 |
| 6. Rye | 1 lb, cult., rye | 71 | Cultivate | 55 | Cult., buck. | 80 |
| 7. Rye | 1 lb, cult., rye | 71 | 1 lb post | 61 | Cult., buck. | 86 |
| 8. Rye | 1 lb, cult., rye | 71 | Cultivate | 55 | Cult., sudan | 88 |
| 9. Rye | 1 lb, cult., rye | 71 | 1 lb post | 61 | Cult., sudan | 84 |
| 10. Rye | 1 lb, cult., rye | 71 | Cultivate | 55 | Oats ½ lb | 48 |
| 11. Rye | 1 lb, cult., rye | 71 | 1 lb post | 61 | Oats ½ lb | 46 |
| 12. Rye | 1 lb, cult., rye | 71 | Oats ½ lb, cult. | 71 | Oats ½ lb | 68 |
| 13. Rye | 1 lb, post, rye | 72 | Cultivate | 18 | Cult., buck. | 82 |
| 14. Rye | 1 lb, post, rye | 72 | 1 lb post | 67 | Cult., buck. | 78 |
| 15. Rye | 1 lb, post, rye | 72 | Cultivate | 18 | Cult., sudan | 82 |
| 16. Rye | 1 lb, post, rye | 72 | 1 lb post | 67 | Cult., sudan | 76 |
| 17. Rye | 1 lb, post, rye | 72 | Cultivate | 18 | Oats ½ lb | 32 |
| 18. Rye | 1 lb, post, rye | 72 | 1 lb post | 67 | Oats ½ lb | 30 |
| 19. Rye | 1 lb, post, rye | 72 | Oats ½ lb, cult. | 72 | Oats ½ lb | 64 |
| 20. Rye | 1 lb & 1 lb, rye | 83 | Cultivate | 34 | Cult., buck. | 90 |
| 21. Rye | 1 lb & 1 lb, rye | 83 | 1 lb post | 73 | Cult., buck. | 82 |
| 22. Rye | 1 lb & 1 lb, rye | 83 | Cultivate | 34 | Cult., sudan | 82 |
| 23. Rye | 1 lb & 1 lb, rye | 83 | 1 lb post | 73 | Cult., sudan | 86 |
| 24. Rye | 1 lb & 1 lb, rye | 83 | Cultivate | 34 | Oats ½ lb | 48 |
| 25. Rye | 1 lb & 1 lb, rye | 83 | 1 lb post | 73 | Oats ½ lb | 30 |
| 26. Rye | 1 lb & 1 lb, rye | 83 | Oats ½ lb, cult. | 83 | Oats ½ lb | 84 |
| 27. Rye | ½ lb & 1 lb, rye | 80 | Cultivate | 45 | Cult., buck. | 90 |
| 28. Rye | ½ lb & 1 lb, rye | 80 | 1 lb post | 76 | Cult., buck. | 82 |
| 29. Rye | ½ lb & 1 lb, rye | 80 | Cultivate | 45 | Cult., sudan | 88 |
| 30. Rye | ½ lb & 1 lb, rye | 80 | 1 lb post | 76 | Cult., sudan | 88 |
| 31. Rye | ½ lb & 1 lb, rye | 80 | Cultivate | 45 | Oats, ½ lb | 62 |
| 32. Rye | ½ lb & 1 lb, rye | 80 | 1 lb post | 76 | Oats, ½ lb | 46 |
| 33. Rye | ½ lb & 1 lb, rye | 80 | Oats ½ lb & 1 lb | 80 | Oats, ½ lb | 72 |

Mean rye yields (bu/A): untreated, 16.4; ½ lb 2,4–D, 14.0; 1 lb 2,4–D, 14.0

[a] "Lb" refers to amount of 2,4–D applied per acre; "post" to post harvest application of 2,4–D; "buck." to buckwheat and "cult." to intensive cultivation.

During the first fall all plots were plowed. Plots receiving treatments 3 to 33 were seeded to winter rye at the rate of 2 bushels per acre.

During the second year plots receiving treatments 1 and 2 were cultivated intensively at 2-week and 3-week intervals, resulting in 96 and 92 percent elimination of spurge, respectively. All cultivations were performed with a 7-foot field cultivator equipped with nine 12-inch sweeps that overlapped. All operations were done at a depth of about 4 inches.

Plots receiving treatments 3 to 5 were harvested, plowed once after harvest, cultivated twice, and seeded to a second rye crop. Ten percent of the leafy spurge was killed.

Treatments 6 to 12 were like treatments 3 to 5, except that they included a spring application of 1 pound acid equivalent of an ethyl ester of 2,4–D per acre shortly before the rye reached the boot stage

of growth in addition to the harvesting, post-harvest plowing and cultivating, and the seeding of a second rye crop. Treatment 12 included an extra cultivation instead of the second rye crop. Seventy-one percent of the spurge was eliminated by these treatments indicating that the spring application of 2,4–D was very helpful in eliminating the weed.

Treatments 13 to 19 were like treatments 6 to 12 except that the application of 2,4–D was made in the stubble after harvest. This allowed time for the post-harvest plowing, but no duckfooting before the second crop of rye was seeded. Treatment 19 included a cultivation, however, because rye was not seeded. Seventy-two percent of the spurge was killed indicating that the post-harvest spraying was as effective as the spring spraying.

Treatments 20 to 26 included a combination of a spring application of 1 pound of 2,4–D as in treatments 6 to 12, and a post-harvest treatment of 1 pound as in treatments 13 to 19. The percent kill was increased to 83 percent, indicating that the additional 2,4–D application was helpful.

Treatments 27 to 33 were similar to treatments 20 to 26 except that only one-half pound of 2,4–D was applied in the spring treatment. Since 80 percent of the spurge was eliminated, indications are that the 1-pound rate used in treatments 20 to 26 was not superior to the one-half pound rate used in these treatments.

During the third year the intensive cultivation used in treatments 1 and 2 killed the remainder of the leafy spurge plants. These results indicate that the 3-week interval, which required 8 cultivations per year, was as effective as the 2-week interval with 10 operations.

Treatments 3 and 4 included 3 cultivations before buckwheat or sudangrass was seeded during late June. Buckwheat seed and sudangrass forage were harvested during early September, and the stubble was fall plowed. These treatments killed 50 and 60 percent of the spurge, respectively.

Treatment 5 included the harvesting of the rye crop, post-harvest plowing, and 2 cultivations before a third crop of rye was seeded. The stand of spurge was reduced an additional 12 percent. Treatments 6, 8, 10, 13, 15, 17, 20, 22, 24, 27, 29, and 31 were similar to treatment 5 except that a third crop of rye was not seeded. In each case the spurge became thicker than it was at the end of the previous year.

Treatments 7, 9, 11, 14, 16, 18, 21, 23, 25, 28, 30 and 32 substituted a 1-pound application of 2,4–D in August and fall plowing for the plowing and cultivation used in the majority of the other treatments. In each case the stand of spurge became thicker.

Treatments 12, 19, 26 and 33 included the seeding of an oats crop, which was sprayed with one-half pound of ester when the grain was in the 5-leaf stage. The stubble was plowed and cultivated twice. The stand of leafy spurge was not affected. The results once again point to the usefulness of a spring application of 2,4–D.

During the fourth year, 18 treatments included three spring culti-

vations followed by a close-drilled seeding of buckwheat or sudangrass, which was harvested in early September. Buckwheat was harvested for seed and sudangrass for forage and the stubble was plowed. Both crops increased the percentage kill of leafy spurge to between 75 and 90 percent. The percentage kill at the end of the previous year appeared to have little effect on the results.

Eleven treatments included an oats crop that was sprayed with one-half pound of 2,4–D during the spring. In each case the treatment failed to increase the percentage of elimination beyond the point reached the previous year, and in half of the cases, the stand increased somewhat.

Treatment 5 included 3 years of the old "fallow-rye" method. It eliminated 52 percent in 3 years.

*Perennial crops, cultivation, and 2,4–D.*

Three experiments involving the use of perennial forage crops, cultivation, and 2,4–D were conducted. They were initiated in August, 1950, 1951, and 1952, and were completed during May, 1954, 1955, and 1956. Each experiment included the same 44 treatments. Each treatment was repeated once in a randomized block design. Weed counts were made on 4 square-yard areas of each plot in mid-May each year. Twenty-four of the treatments and the mean percentage elimination for the 3 experiments are given in Table 2. The other 20 treatments were like the last 20 listed in the table, except that only ½ lb/A of 2,4–D was applied. The percentage of elimination was 10 to 30 percent lower.

*Table 2.* The mean percentages of leafy spurge eliminated by the use of perennial crops, cultivation, and 2,4–D (means for 3 experiments).

| First fall | 2nd year | | 3rd year | | 4th year | |
|---|---|---|---|---|---|---|
| | Treatment[a] | Per cent kill | Treatment[a] | Per cent kill | Treatment[a] | Per cent kill |
| 1. Alfalfa | Alfalfa | 62 | Alfalfa | 29 | Alfalfa | 42 |
| 2. Alf-brome | Alf-brome | 56 | Alf-brome | 53 | Alf-brome | 79 |
| 3. Brome | Brome | 5 | Brome | 39 | Brome | 69 |
| 4. Plow | Cult., brome | 95 | Brome | 97 | Brome | 96 |
| 5. Plow | Cult., brome | 95 | 1 lb May | 96 | Brome | 93 |
| 6. Plow | Cult., brome | 93 | 1 lb June | 98 | Brome | 94 |
| 7. Plow | Cult., brome | 95 | 1 lb Sept. | 99 | Brome | 99 |
| 8. Plow | Cult., brome | 95 | 1 lb May & Sept. | 98 | Brome | 97 |
| 9. Brome | 1 lb May | 49 | Brome | 66 | Brome | 79 |
| 10. Brome | 1 lb June | 45 | Brome | 58 | Brome | 76 |
| 11. Brome | 1 lb Sept. | 21 | Brome | 59 | Brome | 71 |
| 12. Brome | 1 lb May & Sept. | 52 | Brome | 60 | Brome | 75 |
| 13. Brome | Brome | 5 | 1 lb May | 45 | Brome | 61 |
| 14. Brome | Brome | 5 | 1 lb June | 61 | Brome | 68 |
| 15. Brome | Brome | 5 | 1 lb Sept. | 60 | Brome | 66 |
| 16. Brome | Brome | 5 | 1 lb May & Sept. | 60 | Brome | 58 |
| 17. Brome | 1 lb May | 49 | 1 lb May | 74 | Brome | 78 |
| 18. Brome | 1 lb June | 45 | 1 lb June | 62 | Brome | 68 |
| 19. Brome | 1 lb Sept. | 21 | 1 lb Sept. | 65 | Brome | 77 |
| 20. Brome | 1 lb May & Sept. | 52 | 1 lb May & Sept. | 66 | Brome | 81 |
| 21. Brome | 1 lb May | 49 | Brome | 73 | 1 lb May | 84 |
| 22. Brome | 1 lb June | 45 | Brome | 44 | 1 lb June | 80 |
| 23. Brome | 1 lb Sept. | 21 | Brome | 70 | 1 lb Sept. | 85 |
| 24. Brome | 1 lb May & Sept. | 52 | Brome | 81 | 1 lb May & Sept | 91 |

[a] "Lb" refers to amount of 2,4–D applied per acre; and "cult." to intensive cultivation.

All plots were plowed during August the first summer. Treatments 1 and 2 consisted of seeding alfalfa and an alfalfa-bromegrass mixture, while treatments 3 and 9 to 24 included the seeding of bromegrass. Alfalfa was seeded at the rate of 8 lb/A and bromegrass at 12 lb/A. A top dressing of 200 lb/A of 16–20–0 fertilizer was "disked in" prior to seeding. One peck of oats per acre was seeded as a companion crop. The grasses were mixed with the oats and seeded with them.

During the second year, plots receiving treatments 5 to 8 were cultivated every 2 weeks with a duckfoot cultivator from mid-May until mid-August, when the bromegrass was seeded in the same manner as was used the previous fall. The stand of spurge was reduced 95 percent.

One crop of hay was harvested from bromegrass plots and two from plots containing alfalfa. One lb/A of an ethyl ester of 2,4–D was applied in treatments 9 to 12 and 17 to 24 on the dates indicated in Table 2. Between 21 and 52 percent of the leafy spurge was killed by these treatments. More spurge was killed by mid-May or late June applications than by early September treatments, and the spring sprayings were equal to 2 sprayings made in May and September.

Alfalfa seeded alone or in a mixture with bromegrass was more effective than bromegrass seeded alone but less effective than an alfalfa-bromegrass mixture. In one experiment, exceptionally good stands of alfalfa were obtained. By the end of the second year, it appeared that the leafy spurge was eliminated. However, the second mowing was delayed until September 1 to show the results on a field day. The late mowing resulted in considerable winterkilling. The thinned stand of alfalfa allowed the spurge to regain vigor the next year.

During the third and fourth year, the stand of leafy spurge was reduced whenever 2,4–D was applied, and the date of application did not appear to be important. Bromegrass appeared to have enough competitive ability to reduce spurge stands after the plants had been weakened by cultivation or a 2,4–D application. The only treatments that eliminated 90 percent of the spurge in 3 years included a short season of intensive cultivation the first year. Although plots receiving the cultivation produced only 2 crops of hay, they produced a total of 4.9 tons of hay, while those producing 3 crops yielded a total of 5 tons.

One-half of each bromegrass plot received a top dressing of 100 pounds of 33.5–0–0 fertilizer during May of each year, and alfalfa plots received 200 pounds of 0–46–0. Separate leafy spurge counts were made on each half. The mean percentage elimination was 76 percent on the fertilized half and 75 percent on the unfertilized half, indicating that the fertilizer did not increase the competitive effect of the crop.

*Soil sterilants.*

Three experiments were conducted to determine the optimum

rate of application of numerous soil sterilants for the elimination of small patches of leafy spurge. In each experiment, the chemicals were compared at 2 dates—late July and mid-September. Shortly after treatment the plots were observed to determine which chemicals were faster acting. The following year the effects of the chemicals on the weed and the grass sod infested with the weed were noted. Each succeeding year, the plots were plowed and seeded to oats to determine the length of time that the chemicals would inhibit small grain production. The treatments and data are shown in Table 3.

*Table 3.* The minimum rate of soil sterilants required to give 95 per cent elimination of leafy spurge—speed of top kill and years of residual effect.

| | Lb per sq rd[a] | Top kill[b] | Residual effect, years |
|---|---|---|---|
| **Boron carriers** | | | |
| Borascu[g] [g] | 15 | 11 | 3–5[d] |
| Concentrated Borascu[h] | 8–10 | 9 | 3–5[d] |
| Polybor[i] | 8–10 | 8 | 3[d] |
| **Chlorates** | | | |
| Sodium chlorate | 4–5 | 5 | 3–4 |
| Atlacide[k] | 6–8 | 5 | 3–4 |
| **Borate-chlorate mixtures** | | | |
| Polybor-chlorate[m] | 8–10 | 6 | 3 |
| Chorax[n] [n] | 8–10 | 6 | 3–4 |
| **Borate-chlorate-monuron mixtures[e]** | | | |
| Chlorea[o] | 5–8 | 7 | 2 |
| Ureabor[p] | 8 | 10 | 3+ |
| **Borax–2,4–D mixture[e]** | | | |
| DB Granular[r], dry | 5–7 | 4 | 1 |
| DB spray | 5 | 3 | 1 |
| Ammonium sulfamate, 80% (Ammate) | 5 | 1 | 1 |
| **Substituted urea compounds[e]** | | | |
| Monuron | [f] | [f] | 5 |
| Diuron | [f] | [f] | 4+ |
| Fenuron | [f] | [f] | 3 |
| Erbon (Baron) | 0.5–1 | 2 | 2 |

[a]Amount of active ingredient for substituted ureas and erbon and amount of product for all others.
[b]No. 1 caused quickest top kill and No. 11 the slowest.
[c]Included in only one experiment.
[d]Kochia and Russian thistle produced rank growth the second year after treatment.
[e]Included in only two experiments.
[f]One-half pound failed to kill over 30 per cent of spurge.
[g]Sodium borate ore, 34% boron trioxide.
[h]Sodium borate ore, 61.5 per cent boron trioxide.
[i]Disodium octaborate tetrahydrate (64 per cent boron trioxide).
[k]Sodium chlorate 58 per cent.
[m]Disodium octaborate tetrahydrate 73 per cent (49 per cent boron trioxide), sodium chlorate 25 per cent.
[n]Sodium metaborate 58 per cent, sodium chlorate 40 per cent.
[o]Sodium metaborate 57 per cent, sodium chlorate 40 per cent, monuron 1 per cent.
[p]Disodium tetraborate pentahydrate 63.2 per cent, disodium tetraborate decahydrate 30.8 per cent (41.5 per cent boron trioxide), monuron 4 per cent.
[r]Disodium tetraborate pentahydrate 55 per cent, disodium tetraborate decahydrate 35.5 per cent (39.2 per cent boron trioxide), 2,4–D, 7.5 per cent.

All chemicals were more effective when applied during the fall. The lower rate shown in Table 3 was effective when applied in September, but the higher rate was sometimes needed for July applications.

At these rates of application, bromegrass, crested wheatgrass and bluegrass sods were damaged the least by borax–2,4–D mixtures, fol-

lowed by borax compounds and ammonium sulfamate. All compounds containing sodium chlorate, erbon or substituted ureas killed practically all of the grasses. On one occasion, sodium chlorate did not kill bluegrass; a heavy rain fell shortly after application of the chemical and apparently leached it into the soil below the grass roots.

*Other chemicals.*

Numerous other chemicals were tested for their effect on leafy spurge. Three of them showed promise of being useful for controlling the weed. The tests were conducted on plots 1 rod by 3 or 5 rods. All treatments were repeated once in half the experiments and were repeated twice in the others in a randomized block design.

*TBA.* In 4 experiments conducted during 1955–58, 2,3,6–trichlorobenzoic acid was applied at rates of 1 to 6 lb/A acid equivalent to leafy spurge that was 6 to 12 inches tall during mid-May. Approximately 10 days later, the spurge was plowed under and corn was planted. The corn was cultivated 3 times, and ⅓ lb/A of 2,4–D ester was applied to some plots near the time of the second cultivation. An ethyl ester was used in some of the experiments and a butoxyethanol ester in others. There was no damage to the corn in these four experiments or in one of two similar tests conducted on Russian knapweed. However, corn was killed in one Russian knapweed test.

Three of the leafy spurge experiments have been completed. Rates of 4 to 6 lb/A. killed 80 to 90 percent of the spurge. The application of 2,4–D did not improve the results.

In three experiments conducted during 1956–58, 2,3,6–TBA was applied in grain stubble during late August, and the stubble was plowed 10 days later. In two of the experiments, ⅓ lb/A of 2,4–D ethyl ester had been applied when the grain was in the 5-leaf stage of growth. Rates of 4 and 6 lb/A TBA killed 75 to 85 percent of the spurge. The 2,4–D prevented the spurge from producing seed, but did not appear to aid in killing the spurge. Residual effect of the 6-pound rate was to reduce the yield of oats, planted the year following the 1956 experiment, by 15 percent, but there was no effect on corn planted the year following the 1957 experiment.

Two-year experiments utilizing 2,3,6–TBA before corn 1 year and after grain the next or vice versa have been initiated.

*Amitrol.* During early June for each of 2 years, 3–amino–1,2,4–triazole was applied to leafy spurge growing in bromegrass sod. A rate of 8 lb/A, active ingredient, gave 99 percent elimination each year, and killed about 75 percent of the bromegrass. Similar applications made in cultivated land were not satisfactory.

Amitrol was also applied in the experiments with TBA during mid-May before planting corn and during mid-August in grain stubble. Rates of 4, 6, and 8 lb/A, active ingredient, applied during the spring, killed 70 to 80 percent of the spurge without injuring the corn. The application of 2,4–D in the corn did not influence the results. Similar rates, applied in the stubble, killed less than 30 per-

cent of the spurge in the 1956 experiment, which did not receive a 2,4–D treatment in the grain. However, these rates killed 60 to 75 percent of the spurge in the 1957 experiment after ⅓ lb/A of 2,4–D ester had been applied in the grain.

*Silvex.* Ten pounds acid equivalent of 2–(2,4,5–trichlorophenoxy)-propionic acid per acre were applied to leafy spurge growing in bromegrass in two experiments. Application during early June or mid-August eliminated 99 percent of the spurge in each experiment.

Silvex also was applied in some of the experiments with TBA and amitrol—during mid-May before planting corn and during mid-August in grain stubble. Rates of 10 and 20 pounds acid equivalent per acre, applied during the spring, were not effective on the spurge and damaged the corn in two experiments. Rates of 10, 15, and 20 pounds per acre, applied in the stubble, killed less than 40 percent of the spurge in the 1956 experiment, which did not receive a 2,4–D treatment in the grain. However, a 10-pound rate killed 82 percent of the spurge in the 1957 experiment, after ¼ lb/A of 2,4–D ester had been applied in the grain. The residual effect of the 20-pound rate was to reduce the yield of oats, planted the year following the 1956 fall treatment, by 30 percent.

## DISCUSSION

Leafy spurge apparently is more difficult to eliminate than field bindweed. Although intensive cultivation appears to be equally effective on both species, the competitive crops and 2,4–D appear to be less effective on spurge.

In this study, intensive cultivation eliminated over 90 percent of the spurge in 1 year and 100 percent in less than 2 years, regardless of whether the operations were performed at 2- or 3-week intervals. Similar results have been obtained by cultivating spurge with a duckfoot cultivator every 2 to 3 weeks (6) or with a spring-tooth harrow twice each week (2). Spurge appears to be similar to bindweed as the latter was completely eliminated in 2 years or less when duckfoot cultivated at 3-week intervals for the entire season[4] (11, 13).

The "fallow-rye" method, which has been successfully used for the elimination of bindweed[4] (3, 11, 13), was less effective for killing spurge. The stand reduction was 10, 22, and 52 percent at the end of the first, second, and third years, respectively.

Close-drilled crops of sudangrass and buckwheat appeared to be more strongly competitive than other crops used in this study. When three cultivations were performed before seeding and the stubble was plowed after harvest, these crops appeared to have the ability to reduce leafy spurge stands about 50 percent in 1 year and 80 percent in 2 years. Complete elimination of spurge in 2 years has been accomplished when a crop of close-drilled forage sorghum or soybeans was handled in a similar manner (2). However, the results in this study are similar to those obtained with bindweed (3, 11, 13) when forage sorghum or soybeans was used as the competitive crop.

[4]Stahler, L. M., and Derscheid, Lyle A. *Loc. cit.*[3]

Previous work (2) indicates that the seeding of a leafy spurge infested area to a spring-seeded grain is a useless procedure. Similar results were obtained in this study. Spurge starts so early in the spring that it gets ahead of spring-seeded crops. However, an application of ½ lb/A of 2,4–D ester checks weed growth, making it possible for the grain to get ahead and hold the weeds in check. The results indicate that a reduced stand of leafy spurge can be held in check, but not further reduced during a year that a small grain crop is raised if 2,4–D application is made. This leads to the possibility of using some system that will reduce the stand on alternate years with small grain that is sprayed. Alternate years of intensive cultivation and small grain sprayed with 2,4–D is an effective method (6).

Although alfalfa was a good competitive crop for controlling bindweed (3, 11), it did not compete strongly with spurge in this study or in other experiments (2). Leafy spurge emerges at or before the time that alfalfa commences spring growth, and the spurge produces a rank growth which stays ahead of the alfalfa. Bindweed, on the other hand, emerges after alfalfa develops, and its prostrate form of growth allows the alfalfa to overshadow it.

Bromegrass was effective in reducing leafy spurge stands when aided by cultivation or application of 2,4–D. A short season of intensive cultivation prior to a fall-seeded crop eliminated 95 percent of the spurge. Bromegrass was capable of holding the weed in check, without the aid of 2,4–D. However, the stand was not further reduced even when 2,4–D was used.

When the cultivation was omitted, bromegrass that was sprayed with 2,4–D slowly reduced the stand of leafy spurge. The date of treatment appeared to be unimportant although fall treatments were least effective the first year. Two treatments a year did not appear to be superior to 1 treatment.

The results obtained from spring applications of amitrol or 2,3,6–TBA before planting corn and from fall applications made in the stubble of small grain that had been sprayed with 2,4–D indicate that these chemicals may be useful for controlling large infestations of leafy spurge. However, more needs to be learned about using the chemicals, and their price will probably have to be reduced before they are put into widespread use. Numerous investigators have reported in the Regional Weed Conference Research Reports that 2,3,6–TBA was effective on leafy spurge when used at rates 4 or 5 times greater than those used in this study.

The results in this study indicate that numerous soil sterilants can be used to kill small patches of leafy spurge. Some of them appear to be better adapted to certain situations than others. Borax compounds are less apt to injure perennial grasses and appear to be better suited for treating spurge growing in sod. Ammonium sulfamate and borax–2,4–D mixtures have shorter periods of residual effect and appear to be more useful than others in areas that need to be put back in production. Ammonium sulfamate, borax–2,4–D mixtures, and erbon gave quicker top kills and appear to have an

advantage over other chemicals for preventing the production of seed by plants that are budding.

## SUMMARY AND CONCLUSIONS

Three 3-year experiments utilizing 33 combinations of annual crops, cultivation, and 2,4–D application and three 3-year experiments using 44 combinations of perennial forage crops, cultivation, and 2,4–D were initiated during the falls of 1950, 1951, and 1952. Each experiment was replicated in a randomized block design with plots 1 by 5 rods. Weed counts were made each May on 4 one-square-yard areas of each plot. The experiments were terminated with final counts made during May, 1954, 1955, and 1956.

One experiment comparing all commercially available soil sterilants at several rates on two dates of application was conducted each year during 1951, 1952, and 1954 in duplicate 9-foot by 15-foot (½ square rod) plots. The later experiments included more chemicals as they became available. Data on speed of top kill, effect on grass, and period of residual activity as well as effect on weeds were obtained.

Numerous chemicals were screened for possible use in the elimination of large infestations. Amitrol, 2,3,6–TBA, and silvex were applied during the spring, 10 days before plowing and planting corn. They were also applied in grain stubble 10 days before plowing. In some cases 2,4–D was also applied in the crop.

The following conclusions can be drawn:

1. Leafy spurge stands can be materially reduced by use of the proper combination of competitive crop, cultivation, and 2,4–D.
2. Leafy spurge reacts to small amounts of 2,4–D but is not killed by much larger amounts. Ester forms cause much greater reaction than amine forms.
3. Leafy spurge can be eliminated with less than 2 years of intensive cultivation. Operations need not be performed oftener than every 3 weeks if a duckfoot cultivator is operated at a depth of 4 inches.
4. Spring-seeded small grains do not compete favorably with leafy spurge. However, grain sprayed with 2,4–D prevents spurge stands from becoming denser.
5. Sudangrass and buckwheat, where adapted, materially reduce the stand of leafy spurge when the seeding is preceded by three cultivations and harvest is followed by plowing.
6. Alfalfa does not compete favorably with spurge unless a heavier than normal stand of alfalfa is obtained.
7. Bromegrass sprayed with 2,4–D slowly reduces the stand of leafy spurge. It is more effective when fall seeding is preceded by a short season of intensive cultivation.
8. Several soil sterilants can be used to eliminate small patches of leafy spurge.
9. Amitrol and 2,3,6–TBA show great promise for use in eliminating large infestations of leafy spurge. Rates with little

residual effect are effective when their appliaction is followed 10 days later with plowing.

10. Although leafy spurge is affected by methods that have proved to be successful for eliminating field bindweed, leafy spurge is more difficult to eliminate. This is partially due to early emergence, early growth, and rank growth.

## LITERATURE CITED


1. ARNY, A. C. Variations in organic reserves in underground parts of five perennial weeds from late May to November. Minnesota Agr. Exp. Sta. Bul. 84. 1932.
2. BAKKE, A. L. Control of leafy spurge, *Euphorbia Esula* L. Iowa Agr. Exp. Sta. Bul. 222. 1937.
3. ———. Experiments on the control of European bindweed. Iowa Agr. Exp Sta. Bul. 259, pp. 367–440. 1939.
4. ———, GAESSLER, W. G., and LOOMIS, W. E. Relation of root reserves to control of European bindweed *Convolvulus arvensis* L. Iowa Agr. Exp. Sta. Res. Bul. 254. 1939.
5. ———, ———, PLUTZ, L. M., and SALMON, S. C. Relation of cultivation to depletion of root reserves in European bindweed at different soil horizons. Jour. Agr. Res. 69:137–47. 1944.
6. CRAIG, H. A. A leafy spurge eradication program. Proc. NCWCC 14:18–19. 1957.
7. FRANZKE, C. J., and HUME, A. N. Field bindweed and control methods for South Dakota. South Dakota Agr. Exp. Sta. Bul. 305. 1936.
8. FRAZIER, J. C. Advantages of a fourteen-day interval of cultivation for control of field bindweed. Am. Jour. Bot. 28:125. 1941.
9. ———. Nature and rate of development of root system of *Convolvulus arvensis*. Bot. Gaz. 104:417–25. 1942.
10. HANSON, H. C., and RUDD, VELVA E. Leafy spurge—life history and habits. North Dakota Agr. Exp. Sta. Bul. 266. 1933.
11. STAHLER, L. M. Shade and moisture factors in competition between selected crops and field bindweed, *Convolvulus arvensis*. Jour. Am. Soc. Agron. 40:490. 1948.
12. STEVENS, O. A. Handbook of North Dakota Plants. North Dakota Inst. for Regional Studies. Knight Printing Co. Fargo, N. Dak. 1950.
13. TIMMONS, F. L. Results of bindweed control experiments at the Fort Hays Branch Station. Kansas Agr. Exp. Sta. Bul. 296. 1941.
14. ———, and BRUNS, V. F. Frequency and depth of shoot-cutting in eradication of certain creeping perennial weeds. Agron. Jour. 43:371–5. 1951.

# Chemical Control of *Typha angustifolia* L. var. *brownii*

E. Levi[1]

## A.—Factors in the Control by 2,4–D

### Introduction

Typha *angustifolia* L. var. *brownii* (Kunth) Kronf., known as cumbungi in Australia and narrow leaved cattail in the U. S. A., is a deep rooted perennial widely distributed throughout the world. It occurs naturally in swamps and marshy areas and also in irrigation channels, where it may seriously impede the flow of water during the irrigation season. Various mechanical methods of control have beeen devised; the most successful consists of regular cutting and subsequent maintenance of 15 to 18 inches of water above the cut stalks (11). This method was successfully employed in the Murrumbidgee Irrigation Area of New South Wales for many years, but recently has been virtually discarded because of rising labour costs.

The work reported here is part of a study commenced in 1952 in the Murrumbidgee Irrigation Area of New South Wales. The principal objectives of the investigation were to determine whether 2,4–dichlorophenoxyacetic acid (2,4–D) could replace cutting as a method of controlling *Typha* and to elucidate the factors governing its effectiveness.

### Materials and Methods

Solutions or emulsions of a range of 2,4–D formulations were applied by means of a modified pneumatic sprayer delivering liquid at a constant pressure of 60 psi. All materials were applied at volumes of 100 to 150 gpa which were sufficient to completely cover the plants. Nozzles used were of the flat fan type delivering 9.1 gph at 60 psi.

All experiments were of randomized block designs with three or four replications. Plots in all cases were channel sections 9 feet long by 8 feet wide. *Typha* stands used as experimental areas were long established and had not been treated previously with herbicides. The general procedure was to burn the dry material in experimental channels in the spring, just before irrigation water was released, and to apply the treatments when the regrowth was 4 to 5 feet high and had 5 to 7 leaves.

The effect of treatments was assessed by counting or harvesting surviving plants in three quadrats, 1 x 3 feet, in each plot at the end of the growing season. Dry plants were burned the following spring and counts were repeated in early summer to assess regrowth subsequent to treatments. Population densities fluctuated seasonally and for this reason results are presented as per cent of the controls, i.e., the percentage of live plants in treated compared with those in

[1]Senior Research Officer, Division of Plant Industry, Commonwealth Scientific and Industrial Research Organization, Irrigation Research Station, Griffith, New South Wales, Australia.

untreated plots at the different sampling times. Significance of differences was tested by analyses of variance, but because the least significant differences had to be calculated for each individual treatment comparison, it was impracticable to show them.

## EXPERIMENTS AND RESULTS

*1. Stage of growth.*

Four concentrations, 3, 6, 12, and 24 lb/A, of an ethyl ester formulation of 2,4–D containing 22 per cent W/W diesel distillate (11 per cent aromatics) and 41 per cent W/W anionic emulsifier were applied to *Typha* plants at each of two stages of growth: the 5 to 7 leaf stage and flowering. These two growth stages were chosen because there is evidence that they coincide with minimum and rising rhizome reserves, respectively.

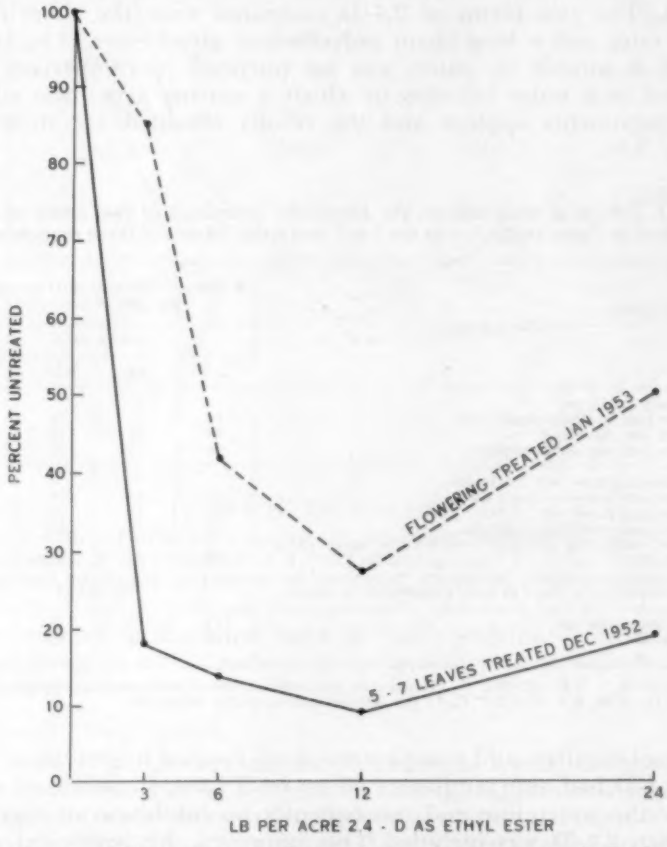



*Figure 1.* Effect of stage of growth on the response of *Typha angustifolia* to 2,4–D. Regrowth expressed as percent of untreated, four months after treatment. Means of three replications.

Water levels in this experiment fell no lower than 12 inches at any time throughout the season. The response curves in relation to dosages and stages of growth are shown in Figure 1.

Figure 1 shows that the response of *Typha* to 2,4–D was greater at the 5 to 7 leaf stage than at flowering ($P < 0.05$).

*2. Formulation.*

The effects of oils of varying phytotoxicities on the penetration and translocation of two esters of 2,4–D were investigated by testing formulations of 2,4–D containing 22 per cent oil and 41 per cent anionic emulsifier. The oils were a relatively nonphytotoxic oil, a slowly toxic diesel distillate and a rapidly toxic petroleum naphtha. The concentrates were emulsified in water.

Two of these oils were applied also as water emulsions without 2,4–D and in amounts equivalent to those in the emulsions with 2,4–D. The two forms of 2,4–D compared were the short chain ethyl ester and a long chain polyethylene glycol ester. The latter, which is soluble in water, was for purposes of comparison also applied as a water solution to which a wetting agent was added. The treatments applied and the results obtained are shown in Table 1.

*Table 1.* Effects of three oils on the herbicidal properties of two esters of 2,4–D applied to *Typha angustifolia* at the 5 to 7 leaf stage. Means of three replications.

| Treatments | Regrowth 4 months after treatment as per cent of untreated | | | |
|---|---|---|---|---|
| | 2,4-D, lb/A | | | |
| | 3.0 | 6.0 | 12.0 | 24.0 |
| Ethyl ester 2,4-D, in: | | | | |
| 22 per cent non-phytotoxic oil[a] | 76 | 23 | 24 | 50 |
| 22 per cent diesel oil[b] | 48 | 30 | 34 | 38 |
| 22 per cent petroleum naphtha | 66 | 53 | 31 | 53 |
| Polyethlyene glycol ester 2,4-D, in: | | | | |
| 22 per cent non-phytotoxic oil[a] | 78 | 35 | 26 | 37 |
| 22 per cent diesel oil[b] | 83 | 59 | 30 | 54 |
| 22 per cent petroleum naphtha | 91 | 74 | 59 | 68 |
| Water containing 0.1 per cent wetting agent (Multi-film L) | 89 | 85 | 63 | 56 |
| Oil + emulsifier + water in same proportions as above: | No. 2,4-D | | | |
| Non-phytotoxic oil[a] | 111 | 103 | 120 | 95 |
| Diesel oil[b] | 111 | 96 | 93 | 122 |

[a]Sp. Gr. 0.77, B.P. 182–282° C, 100 per cent isoparaffinic, free of aromatics and olefins.
[b]Sp. Gr. 0.84, B.P. 235–310° C, 11 per cent aromatics, olefins negligible.

Diesel distillate and non-phytotoxic oil applied in emulsions without 2,4–D had only temporary effects on *Typha;* there was no effect below the water line and consequently no inhibition of regrowth as when 2,4–D was included. Oils improved the herbicidal properties of the polyethylene glycol ester. The less rapidly toxic oils were more effective as carriers than the highly phytotoxic petroleum naphtha.

In another experiment the same three oils were used in 10, 20 and 30 per cent proportion of the concentrates. The ensuing water emulsions applied to *Typha* contained 3, 6, 12, and 24 pounds of 2,4–D per acre in the form of the ethyl ester. It was found that the herbicidal effectiveness of 2,4–D was influenced significantly ($P < 0.001$) by the quantity of petroleum naphtha, but not by the quantities of the less toxic diesel or white oil used in the emulsions. Figure 2 shows that the higher amounts of petroleum naphtha were

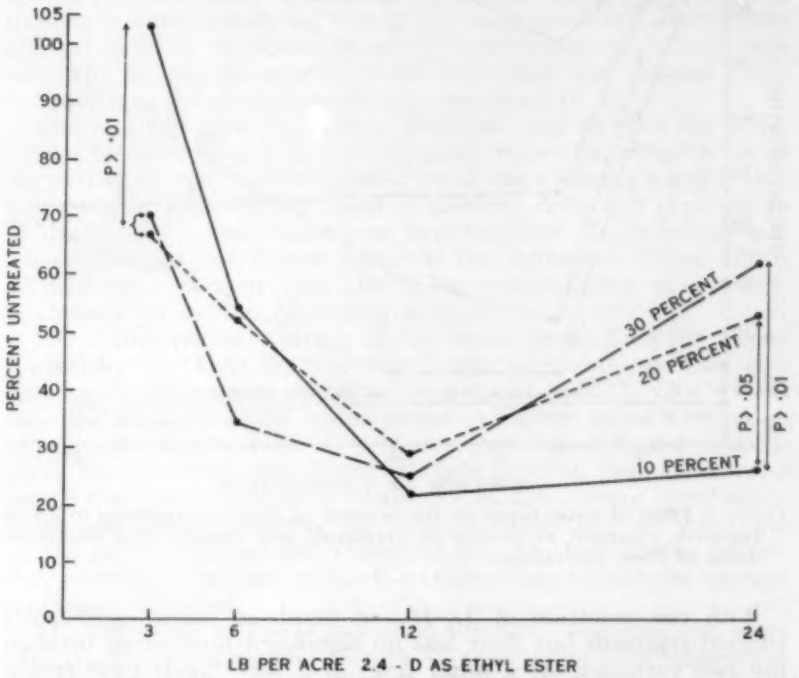



*Figure 2.* Effect of different quantities of petroleum naphtha on the herbicidal effectiveness of 2,4–D applied at a series of dosage rates to *Typha angustifolia*. Regrowth expressed as percent of untreated. Means of three replications.

more effective at the lower rates of 2,4–D and that, at the higher dosage levels of 2,4–D, increasing the quantity of naphtha reduced herbicidal activity.

*3. Effect of water depth.*

In order to determine whether the effect of 2,4–D was related to water levels like that of mechanical cutting, experiments in which the levels of water were controlled subsequent to treatment were carried out over a four year period. Levels were raised 7 to 15 days after 2,4–D treatment and were kept within specified limits for the remainder of the season by small dams over which water flowed continuously.

Figure 3 shows the effects of water level on the survival of *Typha* plants treated with a range of concentrations of 2,4–D and also a comparison of chemical treatment with mechanical cutting at a water level of 3 feet.

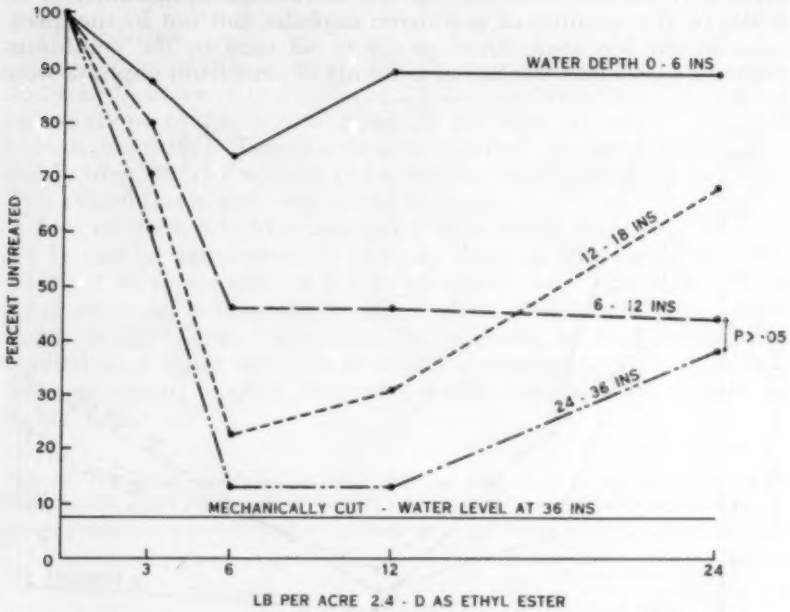



*Figure 3.* Effect of water depth on the response of *Typha angustifolia* to 2,4–D. Regrowth expressed as percent of untreated, four months after treatment. Means of three replications.

Both concentration of 2.4–D and depth of water significantly affected regrowth but there was no significant interaction between the two variables. At a water level of 3 feet, 2,4–D gave results similar to those from mechanical cutting.

## Discussion

Throughout these experiments, 2,4–D, irrespective of formulation, produced a similar sequence of symptoms in *Typha angustifolia*. A partial chlorosis with some leaf tip burn was followed by a more general chlorosis and later by death of the leaves. In the more effective treatments, the plants eventually decayed below water level and completely collapsed. The rapidity at which the above symptoms progressed varied with rate of application. Plants treated with 3 pounds of 2,4–D per acre became chlorotic and often failed to flower, but usually the aerial parts of the plant were not killed. At the highest rates, the foliage was killed rapidly.

A herbicide applied to the foliage of perennials such as *Typha angustifolia* must penetrate the leaf cuticle, move into the meso-

phyll and migrate from there through the vascular system to roots or rhizomes to be effective. The problem is to achieve penetration of the cuticle and entry of sufficient amounts of the herbicide without injuring the tissues severely enough to hinder translocation. Penetration of leaves is determined by the nature of the plant cuticle, by the physicochemical properties of the herbicide and by the way in which it is applied. According to various authors (in particular 1, 13), the cuticle, which is very permeable in new leaves, becomes thicker and less permeable with age. Penetration of 2,4–D in mature leaves was shown to improve when growth regulators were applied in oil or oil emulsions, and it was claimed that the oil saturated the lipophyllic capacity of the leaf cuticle and allowed 2,4–D to move into the phloem in the aqueous phase (1, 4).

The results suggest that slowly phytotoxic oils increase the herbicidal effectiveness of 2,4–D, presumably by aiding penetration of the cuticle (Table 1). On the other hand, the evidence suggests that when highly toxic oils are used as carriers, enhanced penetration of the cuticle is counteracted by rapid killing of plant cells and a consequent lesser translocation of the herbicide. These effects become more marked with increasing concentration of a highly phytotoxic oil such as petroleum naphtha.

For similar reasons there is an optimum dosage level for *Typha* control by 2,4–D. At the 5 to 7 leaf stage of growth the dose in a diesel oil carrier appears to be between 6 and 12 lb/A. This is clear from the dosage response curves shown in Figures 1 and 3 and from some of the data in Table 1. A similar curvilinear dosage response curve was obtained with *Cardaria draba* L. Desv. (10). It was also found that when increasing quantities of 2,4–D were supplied to beans, the amount entering the leaves increased but less was transported to the epicotyl and hypocotyl (6). All these results suggest that applying high rates of 2,4–D to plants may reduce the amount moving to the roots.

The ethyl ester of 2,4–D applied at the 5 to 7 leaf stage was more effective than at flowering (Figure 1), thus confirming suggestions (2) and previous reports in Australia (3).

It was evident that height of water level subsequent to treatment markedly affected the response of *Typha* to 2,4–D (Figure 3), which explains the contradictory results frequently obtained when water levels are uncontrolled and often rather shallow as in drainage channels. The results are of particular interest in view of the successful control of *Typha* obtained by underwater cutting.

The rhizomes of *Typha* contain a high percentage of starch and reducing sugars which under aerobic conditions break down to carbon dioxide and water (11). Under anaerobic conditions the reserve starch is converted to alcohol and organic acids which may be toxic to the underground parts of the plant. It was noted that the leaf bases of 2,4–D treated plants growing in an anerobic environment decomposed rapidly while those similarly treated under dry or shallow water conditions remained in a healthy condition.

The greater effectiveness of 2,4–D under anaerobic conditions, as

evidenced by the lesser regrowth of plants in the deeper water, was confirmed in a pot experiment. Soil blocks containing *Typha* plants were cut in channels, placed in containers, and the plants subsequently treated with 2,4–D. The containers were then immersed at various depths in water. Examination of roots and rhizomes the following spring indicated much greater injury to plants treated with 2,4–D and immersed to depths exceeding six inches.

The results of this series of experiments indicate that 2,4–D or its decomposition products move down the stems of treated plants below the water line; application of non-phytotoxic oil and diesel fuel without 2,4–D failed to kill plants below the water line. It was noted that applying 2,4–D was roughly equivalent to mechanical cuting where water levels in both cases were maintained at 3 feet (Figure 3). These results suggest that there is little or no translocation of 2,4–D from above ground leaves and stems to horizontal rhizomes and that the principal advantages of the chemical are its ability to move down leaves and stems below the water line and its relative ease of application in comparison with cutting.

On a practical basis, 2,4–D spraying is more economical and rapid than hand scything, but more than one application is necessary to keep water flowing unimpeded. Results as yet unpublished indicate that a large degree of control can be expected in supply canals kept full when two applications of 2,4–D at 6 lb/A are applied the same season.

## B.—Control in Drainage Channels

### Introduction

Although water in supply channels is often deep enough to allow successful control of *Typha angustifolia* by 2,4–D spraying, it is seldom so in drainage channels in which levels fluctuate. In these cases a number of 2,4–D applications may be required at regular intervals during a single watering season.

Repeated 2,4–D treatments have greatly reduced or eliminated *Typha* in some channels in the Murray and Murrumbidgee Irrigation Areas in Australia; however, this was followed by a rapid increase in 2,4–D resistant species in the same channels, creating new problems, sometimes as troublesome as the ones originally present (3).

A different chemical which could kill plants at least to soil level following translocation through the water line, and inhibit or delay regrowth of the foliage, was considered of great value in such situations. Two non-volatile herbicides, 3–amino–1,2,4–triazole (amitrol) and 2,2–dichloropropionic acid (dalapon) were reported by various authors to translocate in *Typha* spp and to inhibit growth (5, 7, 8, 12). Both these compounds seemed to offer possibilities for controlling *Typha* in drainage channels, especially amitrol, which was reputed to interfere with photosynthesis. The latter was of particular interest since it was found to kill or effectively inhibit the regrowth of water couch *(Paspalum distichum* L.) for at least 12 months (9).

An experiment comparing the above compounds with an ethyl ester of 2,4–D, the effects of which are reported in part A of this paper, was laid down along the length of a drainage channel in the Murrumbidgee Irrigation Area of New South Wales in 1956.

## METHODS AND MATERIALS

The experimental design and methods followed those described in part A of this paper. Plots were channel sections 9 feet long by 8 feet wide. Water level varied throughout the experiment from 0 to 12 inches. Treatments were of randomized block design with 4 replications, and were applied in the spring when *Typha* plants had reached the 5 to 7 leaf stage.

The ethyl ester of 2,4–D was applied in an oil-water emulsion using a formulation containing 22 per cent diesel oil (11 per cent aromatics) and 41 per cent non-ionic emulsifier. Dalapon and amitrol were applied in water to which 0.1 per cent of a wetting agent (Multifilm L) was added. Rates of the three chemicals were determined by previous experience and no attempt was made to compare them on a pound-for-pound basis. The rates used were, on an acid equivalent basis; 3, 6, 12, and 24 pounds of 2,4–D per acre; 15, 30, and 45 pounds of dalapon (sodium salt) per acre; and 18, 36, and 54 pounds amitrol per acre. All materials were applied at volumes of 100 to 150 gpa which were sufficient to completely cover the plants. Nozzles used were of the flat fan type delivering 9.1 gph at the 60 psi pressure adopted in this experiment.

## RESULTS AND DISCUSSION

The effects of the three herbicides on *Typha* are shown in Figure 4.

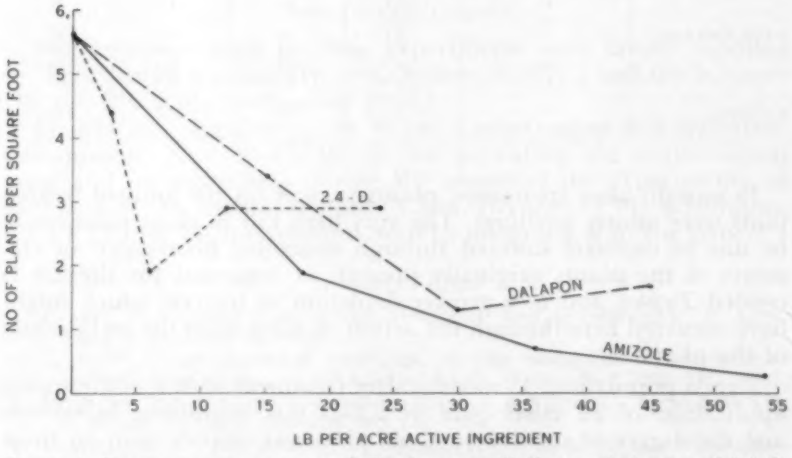



*Figure 4.* Dosage response curves of *Typha angustifolia* to ethyl ester of 2,4–D, amitrol and dalapon at 4 months after treatment. Means of four replications.

As in previous studies, increasing the concentration of the ethyl ester of 2,4–D above 6 pounds per acre, reduced the degree of control measured by regrowth 4 months after treatment. The dalapon dosage response curve was likewise curvilinear, but the optimum dosage was much higher than in the case of 2,4–D. On the other hand, the amitrol curve was almost linear, suggesting a slower phytotoxic action and less interference with translocation at high rates of application than was obtained with dalapon or oil emulsions of 2,4–D in other parts of this experiment.

The breakdown of the leaves and stems of the treated plants was faster and the inhibition of regrowth was of shorter duration in the plots treated with the ethyl ester of 2,4–D than in those treated with either amitrol or dalapon at the rates used. While regrowth was normal following 2,4–D applications, it showed leaf rolling and stunting in plots treated with dalapon. The leaves of amitrol treated plants were killed slowly and there was little regrowth.

The populations of *Typha* on different plots 11 and 15 months after treatment are given in Table 2.

*Table 2.* Effect of single applications of ethyl ester of 2,4–D, amitrol and dalapon when applied to *Typha angustifolia* at the 5 to 7 leaf stage, growing in a drainage channel. Means of four replications.

| Herbicide | Rate of application, lb/A | Plants surviving | | | |
|---|---|---|---|---|---|
| | | 11 months later | | 15 months later | |
| | | No. sq. ft. | Per cent of untreated | No. sq. ft. | Per cent of untreated |
| Amitrol | 18 | 0.4 | 4 | 1.4 | 12 |
| | 36 | 0.2 | 2 | 0.4 | 3 |
| | 54 | 0.1 | 1 | 0.0 | — |
| Dalapon | 15 | 3.3 | 35 | 2.2 | 19 |
| | 30 | 1.3 | 14 | 0.6 | 5 |
| | 45 | 2.5 | 26 | 1.3 | 11 |
| 2.4-D, ethyl ester | 3 | 9.1 | 96 | 9.6 | 85 |
| | 6 | 4.0 | 42 | 5.9 | 52 |
| | 12 | 8.7 | 92 | 5.4 | 48 |
| | 24 | 5.9 | 62 | 5.3 | 47 |
| Untreated | — | 9.5 | 100 | 11.3 | 100 |

15 months after treatment, plants present on the amitrol treated plots were mostly seedlings. The very high kill in those plots could be due to damages suffered through anaerobic breakdown of rhizomes of the plants originally present, as suggested for the 2,4–D treated *Typha*, and to a greater depletion of reserves which might have occurred here through the action of amitrol on the metabolism of the plants.

*Typha* population, 15 months after treatment with a single spring application of an ethyl ester of 2,4–D was beginning to recover and the degree of control on those plots was smaller than on those treated with dalapon and amitrol.

The results establish the efficacy of amitrol and dalapon, in spring applications, for controlling *Typha*, and their possible advantages

over 2,4–D in specific situations such as drainage channels in which water levels are variable, or in areas where although water level can be kept high, 2,4–D treatments are hazardous because of the proximity of sensitive crops.

An added advantage of amitrol is its ability to control other semi aquatic weeds which often become troublesome in channels after *Typha* has been killed. It offers great possibilities for the simultaneous control of water couch *(Paspalum distichum)*, sedge *(Cyperus esculentus)*, dirty Dora *(C. rotundus)*, jointed rush *(Juncus articulatus)* etc. which are often present in association with *Typha* plants, or on the channel banks surrounding the infestations. Although fairly high rates of amitrol are required, the elimination of these weeds would obviously reduce the frequency of channel cleaning operations.

## SUMMARY

The ethyl ester of 2,4–dichlorophenoxyacetic acid (2,4–D), applied at a rate of 6 lb/A (acid equivalent) in an emulsion containing 22 per cent non-phytotoxic oil gave good control of *Typha angustifolia* (cumbungi or cattail) in irrigation channels. The effectiveness of 2,4–D was enhanced when applied at the 5 to 7 leaf stage of growth and when water levels were maintained at a depth of 3 feet subsequent to treatment. The results suggest that 2,4–D acts as a chemical cutter and that the subsequent inhibition of regrowth from *Typha* rhizomes is due to anaerobic conditions under deep water.

In drainage channels, high rates of 3–amino–1,2,4–triazole (amitrol) and 2,2–dichloropropionic acid (dalapon) applied in water solution proved very satisfactory for the control of *Typha* plants growing under conditions of fluctuating water levels. Amitrol gave complete control of *Typha* for at least 15 months after application.

## ACKNOWLEDGEMENTS

The chemicals used in these experiments were kindly supplied by Agricultural Services Pty. Ltd., Sydney (N.S.W.), and the Vacuum Oil Cy. Pty. Ltd., Melbourne (Vict.).

Thanks are also due to the Water Conservation and Irrigation Commission, New South Wales, for providing the experimental areas and for other help during the course of the experiments, as well as to R. M. Moore, Assistant Chief, Division of Plant Industry, C.S.I.R.O., for his interest and help in preparation of the paper.

## LITERATURE CITED

1. CRAFTS, A. S. Herbicides: Their absorption and translocation. J. Agric. Food Chem. 1:51–55. 1953.
2. ———. Translocation of herbicides. I. The mechanism of translocation —Methods of study with $C^{14}$ labelled 2,4–D. Hilgardia 26:287–334. 1957.
3. DUNK, P. Weed control in irrigation channels and drains. Tech. Bull. S.R. & W.S.C., Victoria, Australia, 8:5–14. 1954.
4. GERTSCH, M B. The influence of various carriers upon the inhibitory effectiveness of 2,4–D sprays. Weeds 2:33–42. 1953.
5. GRIGSBY, B. H., REIMER, C. A., and CUTLER, W. A. Observations on the control of cattail *(Typha* spp.) by chemical sprays. Mich. Agri. Exp. Sta. Quart. Bull. 37:400–406. 1955.

6. HAY, J. R., and THIMANN, K. V. The fate of 2,4-dichlorophenoxyacetic acid in bean seedlings. II. Translocation. Plant Physiol. 31:446–451. 1956.
7. HAUSER, E W., and THOMPSON, J. Effects of 3-amino-1,2,4-triazole and derivatives on nut grass and Johnson grass. J. Agri. and Food Chem. 2:680–681. 1954.
8. LEE, W. O., and TIMMONS, F. L. Control of cattail by various chemical treatments. Res. Prog. Rpt. West. Weed Control Conf. pp. 122–123. 1954.
9. LEVI, E. The control of water couch *(Paspalum distichum* L.) in irrigation channels with 3-amino-1,2,4-triazole (amizole). J. Austral. Inst. Agri. Sci. (in press). 1959.
10. MOORE, R. M. Studies on perennial weeds: The control of hoary cress *(Cardaria draba)* by chlorinated phenoxyacetic compounds. Emp. J. Exp. Agri. 22:112–120. 1954.
11. PRUNSTER, R. W. The control of cumbungi *(Typha* spp.) in irrigation channels. J. C.S. & I.R., Australia, 13:1–6. 1940.
12. ROGERS, B. J. Translocation and fate of amino triazole in plants. Weeds 5:5–11. 1957.
13. WEINTRAUB, R. L., YEATMAN, J. N., BROWN, J. W., THORNE, J. A., SKOSS, J. D., and CONOVER, J. R. Studies on entry of 2,4-D into leaves. Proc. Northeastern Weed Control Conf. 8:5–10. 1954.

## News and Notes

The 50th State is right up there in weed control activities. The Hawaii Weed Conference was established in 1954. It is made up of four sections, one on each of the islands of Hawaii, Kauai, Maui, and Oahu. An individual comes in to the Conference as a member of the section on the island where he lives. There are about 250 people who maintain an active interest in the Hawaii Weed Conference.

Meetings were held during August 24 to 31, 1959, on each of the four islands. Field trips were held during the day, followed by dinner in the evening. The speakers at each of the dinners were Dr. H. Wayne Hilton of the Hawaiian Sugar Planters Association Experiment Station, and Mr. Clayton E. Bartley of Geigy Agricultural Chemicals. On the "big island", Hawaii, two additional days of field trips were held.

## Sustaining Members

Amchem Products Company, Ambler, Pennsylvania
American Cyanamid Company, Agricultural Division, New York, New York
American Smelting & Refining Company, Central Research Laboratories, South Plainfield, New Jersey
Asplundh Tree Expert Company, Jenkintown, Pennsylvania
Association of American Railroads, Chicago, Illinois
Chemical Insecticide Corp., Metuchen, New Jersey
Chipman Chemical Company, Inc., Bound Brook, New Jersey
Colloidal Products Corp., Sausalito, California
Crag Agricultural Chemicals Division, Union Carbide Chemicals Co., White Plains, N. Y.
Deere & Company, Moline, Illinois
Diamond Alkali Company, Cleveland, Ohio
The Dow Chemical Company, Midland, Michigan
E. I. duPont deNemours & Co., Inc., Industrial and Biochemical Dept., Wilmington, Del.
Edison Electric Institute, New York, New York
G. L. F. Soil Building Service, Ithaca, New York
Geigy Agricultural Chemicals, Division of Geigy Chemical Corp., Yonkers, New York
General Chemical Research Laboratory, Allied Chemical & Dye Corp., Morristown, N. J.
Hart Equipment Company, Rockton, Illinois
Hercules Powder Company, Wilmington, Delaware
International Harvester Company, Chicago, Illinois
Minerals & Chemicals Corp. of America, Menlo Park, New Jersey
Monsanto Chemical Company, St. Louis, Missouri
National Aluminate Corp., Chicago, Illinois
Naugatuck Chemical Division of United States Rubber Company, Bethany, Conn.
Niagara Chemical Division, Food Machinery and Chemical Corp., Middleport, New York
Oberdorfer Foundries Inc., Pump Division, Syracuse, New York
O. M. Scott & Sons Company, Marysville, Ohio
Spencer Chemical Company, Kansas City, Missouri
Spraying Systems Company, Bellwood, Illinois
Stauffer Chemical Company, New York, New York
Swift & Company (Plant Food Division), Chicago, Illinois
Thompson Chemicals Corp., St. Louis, Missouri
Thompson-Hayward Chemical Company, Kansas City, Missouri
United States Borax & Chemical Corp., Los Angeles, California

# Committees of the Weed Society of America

**Executive Committee**

A. S. Crafts, *President*
K. P. Buchholtz, *Vice-President*
W. C. Shaw, *Secretary*
W. B. Ennis, Jr., *Past President*
Gordon Utter, NEWCC
S. R. Fertig, NEWCC
F. W. Slife, NCWCC
L. A. Derscheid, NCWCC
J. T. Holstun, Jr., SWC
E. G. Rodgers, SWC
W. R. Furtick, WWCC
R. A. Fosse, WWCC
E. J. Willard, *Editor* WEEDS
W. C. Jacob, *Treas.-Bus. Mgr.*

**Program Committee**

K. P. Buchholtz
W. A. Harvey
D. L. Klingman
G. F. Warren
W. C. Shaw, *Chairman*

**Terminology Committee**

| | |
|---|---|
| F. M. Ashton | (5 years) |
| W. Allen | (4 years) |
| R. Behrens | (2 years) |
| L. G. Holm | (1 year) |
| W. C. Shaw, *Chairman* | (3 years) |

**Education Committee**

| | |
|---|---|
| W. R. Furtick | (3 years) |
| L. J. King | (2 years) |
| C. J. Willard | (5 years) |
| C. L. Foy | (1 year) |
| K. P. Buchholtz, *Chairman* | (4 years) |

**Public Relations Committee**

W. C. Jacob
Leonard Lett
W. C. Robocker
Jack Dreessen, *Chairman*

**Finance Committee**

| | |
|---|---|
| W. S. Van Scoik | (3 years) |
| S. M. Raleigh | (4 years) |
| E. D. Rodgers | (1 year) |
| F. L. Timmons | (5 years) |
| F. W. Slife, *Chairman* | (2 years) |

**Legislative Committee**

| | |
|---|---|
| E. A. Epps, Jr. | (4 years) |
| T. J. Muzik | (3 years) |
| J. C. Ward | (5 years) |
| W. S. Ball | (1 year) |
| Jack Dreessen, *Chairman* | (2 years) |

**Sustaining Memberships Committee**

G. D. Hill
A. D. Lohr
R. N. Raynor
A. J. Tafuro
E. R. Marshall, *Chairman*

**Local Arrangements Committee**

P. A. Frank
J. L. Fults
B. J. Thornton
Tom R. Bartley
R. A. Fosse, *Chairman*

**Constitution and By-laws**

G. C. Klingman
M. W. Parker
C. I. Seely
R. H. Beatty
C. J. Willard, *Chairman*

**Resolutions and Necrology**

D. W. Lambert
L. C. Erickson
W. G. Westmoreland
Paul F. Dresher, *Chairman*

**Auditing Committee**

F. W. Slife
R. L. Gantz

**Meeting Policy and Site Committee**

E. G. Rodgers
L. G. Utter
K. P. Buchholtz
C. J. Willard
A. S. Crafts
W. B. Ennis, Jr., *Chairman*

**Editorial Committee**

O. C. Lee
R. A. Peters
W. C. Robocker
E. G. Rodgers
C. J. Willard, *Chairman*

# BIBLIOGRAPHY OF WEED INVESTIGATIONS
## for
## April, May, June, 1959

## Table of Contents


| | *Reference Number* |
|---|---|
| I. Economic Aspects and General Weed Problems | 1 |
| II. Botany of Weeds | |
| A. Classification and Identification | 50 |
| B. Ecological Investigations and Surveys | 60 |
| C. Physiological Investigations | 72 |
| D. Morphological and Anatomical Investigations | 122 |
| E. Weed Seed Investigations | — |
| III. Weed Control | |
| A. Cultural | 128 |
| B. Chemical | |
| 1. Weeds in field crops | 134 |
| 2. Weeds in horticulture, ornamental and vegetable crops | 182 |
| 3. Weeds in grasslands, including grass-legume pastures, rangeland, turf, lawns, and cemeteries | 218 |
| 4. Weeds in specialized areas, including ditchbanks, canal ditches, fencerows, rights-of-way, irrigation ditches, and cities | 234 |
| 5. Woods plants | 243 |
| 6. Aquatic weeds | 254 |
| 7. Specific weeds | 256 |
| C. Biological | 291 |
| IV. Chemical and Biochemical Investigations | 293 |
| V. Special Characteristics of Weeds | |
| A. Poisonous Plants and Their Control | 304 |
| B. Uses of Weeds | — |
| C. Pathological and Entomological Relationships | 314 |
| VI. Nature and Properties of Chemicals Used as Herbicides | 315 |
| VII. Effect of Herbicides on Soils, Livestock, and Humans | — |
| VIII. Equipment, Methods of Application, and Herbicidal Calculations | 346 |
| IX. Legal Aspects | 353 |



Prepared By

UNITED STATES DEPARTMENT OF AGRICULTURE

Agricultural Research Service
Crops Research Division
Weed Investigations Section


This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Crops Research Division, Agricultural Research Service, U.S.D.A. does not assume responsibility for the subject matter cited.


Beltsville, Maryland

## I. Economic Aspects and General Weed Problems


1. Albert, W. B. The MBC's of weed control: its mechanical (M), biological (B), and chemical (C) aspects. South. Weed Conf. Proc. 10:1–5. 1957.
2. Barrie, A. G. Better pre-emergence weedicides—at a price. Queensland. Bur. Sugar Expt. Sta. Cane Growers' Q. B. 22 (2):47–48. Oct. 1, 1958.
3. Bleasdale, J. K. A. The yield of onions and red beet as affected by weeds. J. Hort. Sci. 34 (1):7–13. Jan. 1959.
4. Blixt, B. Weed control. (In Swedish.) Hallands Läns Hushsällsk. Tidskr. 3:15–17. 1958.
5. Boehm, A. W. Farming with hormones. Fortune 59 (4):144–146, 180, 184, 186, 189. Apr. 1959.
6. Canada. National Weed Committee. Eastern Sect. Reesarch report, 1958. n.p., 1958. 138 p.
7. Cartier, R. D. Les mauvaises herbes dans les grandes cultures du Québec. Agriculture [Montreal] 15 (5):139–140, 160. Sept./Oct. 1958.
8. Chaffin, W. Control of weeds in Oklahoma. Okla. State U. Agr. Ext. C. E–582, 31 p. Oct. 1958.
9. Ciferri, R. Significance of chemical selective weed control on the farm. (In Italian.) Colt. e Gior. Vinic. Ital. 105 (1):9–11. Jan. 1959.
10. Conover, H. S. Grounds maintenance handbook. Ed. 2. New York, F. W. Dodge Corp., 1958. 501 p.
11. Denmark. Statens Ukrudtsforsøg. The Danish Institute for Weed Research, 1957. (In Danish.) Tidsskr. f. Planteavl 62 (4):615–626. 1958.
12. Duckworth, W. Chemical weed control is making definite progress. Spreckels Sugar Beet B. 23 (1):3. Jan./Feb. 1959.
13. Evans, S. A. British Weed Control Conference. Gt. Brit. Min. Agr. Fisheries & Food. Agriculture 65 (10):503–506. Jan. 1959.
14. Featherstone, C. I. The progress of chemical weed control in Hawke's Bay. New Zeal. Weed Control Conf. Proc. 10:7–12. 1957.
15. Ferens, P. S. The place in New Zealand farming for the chemical ploughing technique. Massey Agr. Col. Sheepfarming Annu. 1958:177–182.
16. Fleming, S. D. Perennial grasses as a limiting factor in tropical agriculture and methods for their control. (Abs.) World Crops 11 (1):23–24. Jan. 1959.
17. Forbes, J. Report on spraying in Western Canada. Farm Equip. Dealer 14 (11):17–20, 22. Nov. 1958.
18. Gentner, W. A., Shaw, W. C., and Jansen, L. L. A visual aid for illustrating herbicidal chemical structures and teaching chemical nomenclature. Weeds 7 (1):98–103. Jan. 1959.
19. Graaf, A. J. V. D. Chemical weed control. (In Dutch.) Boskoop. Ver. Proefsta. v. de Boomkwekerij. Jaarb. 1957:80–86.
20. Granström, B. Weed control in the fall. (In Swedish.) Jönköpings Läns Hushsällsk. Tidskr. 3:10–11. Sept. 1958.
21. Grümmer, G. Die Beeinflussung des Leinertrages durch Camelina-Arten. Flora [Jena] 146 (1/2):158–177. Aug. 20, 1958.
22. Gudmundsson, A. Weed control. (In Icelandic.) Búnaoarfélags Isl. Búnaoarrit 71:315–335. 1958.
23. Hattingh, E. R. Weed problems and control practices in South Africa. (Abs.) World Crops 11 (1):24. Jan. 1959.
24. Healy, A. J. Horticultural discards may become national weeds. New Zeal. Plants & Gard. 2 (8):333–338. Sept. 1958.
25. Helgeson, E. A. La lucha contra las malas hierbas herbicidas. Tierra [México] 13 (12):1072, 1128. Dec. 1958.
26. Helgeson, E. La lucha contra las malas hierbas. Tierra [México] 13 (9): 792, 847–849. Sept. 1958.
27. Hill, G. D. Present and future prospects suggest rapid progress in the war on weeds. Crops & Soils 11 (3):7–8. Dec. 1958.
28. King, L. J. On the origin of the term "weed." Ind. Acad. Sci. Proc. 67: 287–289. 1957, pub. 1958.
29. Lewis, K. H. C. The effect of spraying on fat lamb production. New Zeal. Weed Control Conf. Proc. 10:44–47. 1957.

30. Lindegaard, J., and Pedersen, H. E. Tests and investigations of chemicals for the control of plant diseases, pests and weeds. (In Danish.) Beret. om Faellesforsøg i Landbo- og Husmandsforgerne. 1958:3–44. 1959.
31. Loewel, E. L., and Mohs, H. J. Zur Unkrautbekämpfung im Obstbau. Obstbauversring. des Alten Landes. Mitt. 13 (8/9):260–261. Aug./Sept. 1958.
32. Lynch, P. B. Some comparisons of weed control problems in the British Isles and New Zealand. New Zeal. Weed Control Conf. Proc. 10:48–54. 1957.
33. Matthews, L. J. Review of weed control in New Zealand. New Zeal. Weed Control Conf. Proc. 10:13–17. 1957.
34. New Zealand Weed Control Conference. Proceedings of the tenth conference held at Napier 2nd to 5th July 1957. Wellington, 1957. 114 p.
35. Nilsson-Leissner, G. Wild oats in empty sacks—danger for the farmer. (In Swedish.) Älvsborgs Läns Norra Hushsällsk. Tidskr. 65 (4):11. 1958.
36. O'Neil, J. M. Questions and answers on weed control. So. Austral. Dept. Agr. J. 62 (2):75–79. Sept. 1958.
37. Palfrey, G. D. Use of herbicides on vegetables, pastures, and brush in the Atlantic Provinces. Agr. Pesticide Tech. Soc. Proc. 5:65–68. 1958.
38. Poignant, T. Traitements herbicides contre les plantes adventives hebergeant des vecteurs de virus. (Sum.) Rev. de Path. Gén. et de Physiol. Clin. 58 (703):1793–1794. Dec. 1958.
39. Rademacher, B. Grundlagen und Methoden neuzeitlicher Unkrautbekämpfung. Förderungsdienst 6 (11):328–335. Nov. 1958.
40. Rademacher, B. Grundlagen und Methoden neuzeitlicher Unkrautbekämpfung. Förderungsdienst 6 (12):363–366. Dec. 1958.
41. Roberts, H. A. A review of the use of herbicides in British vegetable production. Empire J. Expt. Agr. 26 (104):283–292. Ref. Oct. 1958.
42. Santelmann, P. W., and Duncan, A. A. Keeping extension agents and dealers informed on weed control. Weeds 7 (1):104–107. Jan. 1959.
43. Southern Weed Conference. Proceedings, eleventh annual meeting, January 13, 14, 15, 1958, Memphis, Tennessee. n.p., 1958. 122 p.
44. Southern Weed Conference. Proceedings, tenth annual meeting, January 23, 24, 25, 1957, Augusta, Georgia. n.p., 1957. 273 p.
45. Thompson, G. D., and Trichardt, H. Observations and results with weedkillers at Illovo. So. African Sugar Technol. Assoc. Proc. 31:125–128. 1957.
46. Verma, R. D., Bhardwaj, R. B. L., and Raheja, P. C. Progress of chemical weed control in India. Indian J. Agron. 2 (4):243–253. Ref. June 1958.
47. Vidme, T. Control of weeds. (In Norwegian.) Plantevern i Hagebruket 1958:17–21.
48. Weed control in the Tropics. 2. World Crops 11 (1):23–24. Jan. 1959.
49. Westmoreland, W. G., and Carpenter, W. L. Publications in an extension program. South. Weed Conf. Proc. 10:187–189. 1957.

## II. Botany of Weeds

### A. Classification and Identification

50. Glue, D. I., and Matthews, L. J. Weed identification and control: barley grass. New Zeal. J. Agr. 97 (4):313. Oct. 15, 1958.
51. Glue, D. I., and Matthews, L. J. Weed identification and control. New Zeal. J. Agr. 98 (1):24. Jan. 15, 1959.
52. Harker, K. W. An Acacia weed of Uganda grasslands. Trop. Agr. [St. Augustine] 36 (1):45–51. Jan. 1959.
53. Meadly, G. R. W. Weeds of Western Australia: docks (Rumex spp.). West. Austral. Dept. Agr. J. (ser. 3) 7 (6):621–623. Nov./Dec. 1958.
54. Meadly, G. R. W. Weeds of Western Australia: Watsonia. West. Austrl. Dept. Agr. J. (ser. 3) 7 (5):541–543. Sept./Oct. 1958.
55. Meadly, G. R. W. Weeds of Western Australia: wild turnip (Brassica tournefortii Gouan). West. Austral. Dept. Agr. J. (ser. 3) 7 (4):441–444. July/Aug. 1958.

56. O'Neil, J. M. Three weeds which are easily confused: star, saffron and soldier thistles. So. Austral. Dept. Agr. J. 61 (12):558–560. July 1958.
57. Parsons, W. T. Golden thistle, a weed of limited distribution. J. Agr. [Melbourne] 56 (9):591–595, 597. Sept. 1958.
58. Turner, E. C. Witchweed (Striga asiatica) description and recommended control. Clemson Agr. Col. S. C. Ext. C. 445, 12 p. Apr. 1958.
59. Wagner, W. H. The hybrid ragweed, Ambrosia artenisiifolia × trifida. Rhodora 60 (720):309–316. Ref. Dec. 1958.

### B. Ecological Investigations and Surveys

60. Arai, M., and Kataoka, T. Ecological studies on Alopeculus aequalis Sobol., (1) On the influence of soil moisture and of the depth of soil layers over the seeds upon germination and emergence of them. (2) On the temperature for germination and emergence, and seasonal variation in emerging capacity. (In Japanese.) Crop Sci. Soc. Japan. Proc. 24 (4):275–278. July, 1956.
61. Arai, M., and Kataoka, T. Ecological studies on Alopeculus aequalis Sobol., (3) Influence of soil moisture on the dormancy and longevity of seeds. (4) Seasonal variation in the viable seed population and its vertical distribution within soil. (In Japanese.) Crop Sci. Soc. Japan. Proc. 24 (4):319–323. July, 1956.
62. Arai, M., Kataoka, T., and Chisaka, H. Ecological studies on Alopeculus aequalis Sobol., (5) On the influence of light intensity upon growth of the weed, viability of seeds at various stages of maturity and seed production. (6) On the compost and the methods of field management as agents in seed dissemination. (In Japanese.) Crop Sci. Soc. Japan. Proc. 27 (1):129–132. Sept., 1958.
63. Donaldson, C. H., and Mostert, J. W. C. Alarming encroachment of bitterbos in Orange Free State. Farming So. Africa 34 (9):53–56. Dec. 1958.
64. Hawksworth, F. G., and Peterson, R. S. Notes on the hosts of three pine dwarfmistletoes [Arceuthobium spp.] in northern Colorado. Plant Dis. Rptr. 43 (1):109–110. Jan. 15, 1959.
65. Leal, A. R., and Roig, F. A. Los hospedantes de hemiparásitos y parásitos fanerogámicos en el alto Valle de Atuel (Mendoza). Soc. Argentina de Bot. B. 7 (2):116–119. Oct. 1958.
66. Linder, H., and Wik, M. The spreading of wild oats in the Uppsala Province is disquieting. (In Swedish.) Uppsala Läns Hushsällsk. Försök och Undervis. 1957/58:69–79.
67. Mendonça, A. Present state of the problem of Eichhornia crassipes in Mozambique and Angola. Pesticides Abs. & News Sum. Sect. C 4 (4):238–239. Oct. 1958.
68. Oyer, E. B., Gries, G. A., and Rogers, B. J. The seasonal development of Johnson Grass [Sorghum halepense] plants. Weeds 7 (1):13–19. Jan. 1959.
69. Racovitza, A. Carum a jowan Benth et Hook, une nouvelle et intéressante plante nourricière de l'Orobanche ramosa L. d'Agr. Trop. et de Bot. Appl. 5 (6/7):491–496. Ref. June/July 1958.
70. Serrano P., J. L., and Rojas Garciduenas, M. Efectos del control quĭmico y del control por competencia en el desarrollo de malezas en trigo (Triticum vulgare L.) Ciencia 18 (4/6):58–61. Sept. 1, 1958.
71. Wilson-Jones, K. Studies on the weed population of the Sudan Gezira Scheme. (Abs.) World Crops 11 (1):23. Jan. 1959.

### C. Physiological Investigations

72. Andreae, W. A. The effect of maleic hydrazide on indoleacetic acid oxidase activity and growth. Cong. Internatl. de Bot. Rap. et Commun, Deuxième Sér. 8(sect. 11/12):134–135. 1954, pub. 1957.
73. Ashton, F. M., and Sheets, T. J. The relationship of soil adsorption of EPTC to oats injury in various soil types. Weeds 7 (1):88–90. Jan. 1959.
74. Bayer, D. E. Some factors affecting the germination of seeds and plant responses to herbicides of three species of smartweed Polygonum pensyl-

vanicum L., Polygonum persicaria L., and Polygonum lapathifolium L. Diss. Abs. 19 (4):622–623. Oct. 1958.

75. Behrens, R., and Fisher, C. E. Herbicidal and growth inhibitory activity of optical isomers of 2-(2,4,5-trichlorophenoxy) propionic acid. (Abs.) South Weed Conf. Proc. 10:140. 1957.
76. Blackman, G. E., Osborne, D. J., and Novoa, S. Inter-relationships between chemical structure and the physiological effects of plant growth regulators. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):153–156. 1954, pub. 1957.
77. Bocchi, A. Action hypoauxinisante de l'eosine concernant en particulier l'accroissement et le geotropisme des racines. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):150–153. 1954, pub. 1957.
78. Boll, W. G. Inhibition of growth of excised tomato roots by 2-diethylaminoethanol. Science 129 (3345):330–331. Feb. 6, 1959.
79. Buhl, C. Wuchsstoffschäden durch 2,4-D + 2,4,5-T-Ester an Runkel-Rüben. Z. f. Pflanzenkrank. (Pflanzenpath.) u. Pflanzenschutz 65 (9):529–534. Sept. 1958.
80. Burström, H. Growth regulators and cell wall properties of roots. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):141–143. 1954, pub. 1957.
81. Clor, M. A., Currier, H. B., and Stocking, C. R. Growth responses resulting from gibberellic acid and 2,4-D interaction. Bot. Gaz. 120 (2):80–87. Ref. Dec. 1958.
82. Crafts, A. S., and Foy, C. L. Autoradiography of radioactive dalapon. Down Earth 14 (4):2–6. Spring 1959.
83. Datta, S. C., and Dunn, S. Effects of light quality on herbicide toxicity to plants. Weeds 7 (1):55–65. Jan. 1959.
84. Davis, D. E., and Funderburk, H. H. Causes of variability in susceptibility to injury by DNBP. (Abs.) South. Weed Conf. Proc. 10:139. 1957.
85. Davis, D. E., Funderburk, H. H., and Sansing, N. G. Radioactive herbicides aid research. Highlights Agr. Res. [Ala. Sta.] 5 (3):7. Fall 1958.
86. Dunn, S. Light effects on weed-killers. N. H. Prog. Rpt. 4 (2):3–5. June 1958.
87. Farmer, A., Hawkins, J. E., and Roberts, G. E. 2,4,5-T hastens maturity of Oullins and Moorpark Apricots. Orchardist New Zeal. 31 (9):275, 277, 279. Oct. 1958.
88. Ferenczy, L., and Stefandel, I. Investigations on fungistatic activity of auxins. Acta Agron. [Budapest] 8 (3/4):167–170. 1958.
89. Frans, R. E. Kinetics of growth inhibition by herbicides. (Abs.) South. Weed Conf. Proc. 10:141–142. 1957.
90. Gracza, L. Relation between the germination vigour of cereals and the auxin-sensitivity of their coleoptiles. Acta Agron. [Budapest] 8 (3/4):161–165. Ref. 1958.
91. Grosclaude, C. Action de l'acide indole-$\beta$-acétique sur la croissance in vitro de quelques champignons: Coryneum beijerinskii Oud., Fusicoccum amygdali Del., Cytospora leucostoma (Pers.) Sacc. et Stereum purpureum. Acad. des Sci. Compt. Rend. 248 (5):737–740. Feb. 2, 1959.
92. Hardcastle, W. S. The acidity of combinations of certain herbicides as determined by biological assay. Diss. Abs. 19 (7):1529. Jan. 1959.
93. Harrison, S. C. The effect of weedkillers on seed germination. New Zeal. Weed Control Conf. Proc. 10:55–58. 1957.
94. Hauser, E. W., and Thompson, J. T. A study of the absorption and translocation of several chemicals in Johnson grass [Sorghum halepense], and an evaluation of their effectiveness for its control under field conditions. Weeds 7 (1):20–33. Jan. 1959.
95. Helgeson, E. A. Breaking the dormancy of buds in leafy spurge with gibberellic acid. N. Dak. Acad. Sci. Proc. 12:77–78. July 1958.
96. Henderson, J. H. M. The effect of 2,4-D on auxin destruction and respiration. Cong. Internatl. de Bot. Rap. de Commun. Deuxième Sér. 8(sect. 7/8):261–263. 1954, pub. 1957.
97. Henderson, J. H. M. The effect of 2,4-D on auxin destruction and respi-

ration. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8 (sect. 11/12):170. 1954, pub. 1957.

98. Holstun, J. T. A preliminary study of the effects of weeds on cotton. (Abs.) South. Weed Conf. Proc. 10:30. 1957.
99. Jacques-Felix, H., and Alègre, G. Action de l'hydrazide maléique sur Cyperus rotundus. Agr. Trop. [Paris] 13 (6):789–790. Nov./Dec. 1958.
100. Kandler, O. The effect of 2,4–dinitrophenol on respiration, oxydative assimilation, and photosynthesis in Chlorella. Physiol. Plant. 11 (4):675–684. Ref. 1958.
101. Kommedahl, T., Kotheimer, J. B., and Bernardini, J. V. The effects of quackgrass [Agropyron repens] on germination and seedling development of certain crop plants. Weeds 7 (1):1–12. Ref. Jan. 1959.
102. Kordan, H. A. Proliferation of excised juice vesicles of lemon in vitro. Science 129 (3351):779–780. Mar. 20, 1959.
103. Linser, H. Interaction of growth promoters and growth inhibitors. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):145–147. 1954, pub. 1957.
104. Marth, P. C., Audia, W. V., and Mitchell, J. W. Fruit drop control: evaluation of chlorine-substituted phenoxyacetic acids and amides for retarding abscission of apple fruits. J. Agr. & Food Chem. 7 (2):122–124. Ref. Feb. 1959.
105. Hasman, M. Die Beziehungen zwischen der molekularen Struktur verschiedener Wuchsstoffe und der Semipermeabilität lebender Membranen. Naturwissenschaften 45 (23):573. Dec. 1, 1958.
106. Massini, P. Uptake and translocation of 3–amino-and -3–hydroxy- 1, 2, 4, -triazole in plants. Acta Bot. Neerland. 7 (3):524–530. Ref. Oct. 1958.
107. Miller, J. H., Wilkerson, J. A., and Walhood, V. T. Carry-over response of 2,4–dichlorophenoxyacetic acid and 2–methyl–4–chlorophenoxyacetic acid through seed of cotton. South. Weed Conf. Proc. 11:72–73. 1958.
108. Nelson, R. T., and Wood, R. R. Studies of chemical treatments on sugar beets including gibberellic acid, 2,4–D, and maleic hydrazide. Amer. Soc. Sugar Beet Technol. J. 10 (1):76–79. Apr. 1958.
109. Heslop-Harrison, J., and Heslop-Harrison, Y. Long-day and auxin induced male sterility in Silene pendula L. Portugaliae Acta Biol. Sér. A, 5 (2):79–94. Ref. 1958.
110. Moreland, D. E. Some physiological and biochemical aspects of the selective action of herbicidal chemicals. South. Weed Conf. Proc. 10:146–148. 1957.
111. Munakata, K., and Nakai, A. Growth regulator action: absorption and translocation of 2–$I^{131}$–2,3,5–triiodobenzoic acid. J. Agr. & Food Chem. 7 (3):176–178. Mar. 1959.
112. Muzik, T. J., and Cruzado, H. J. Differentiation of bean internode segments in tissue culture with added indoleacetic acid, 2,4–dichlorophenoxyacetic acid, and maleic hydrazide. Bot. Gaz. 120 (1):57–59. Ref. Sept. 1958.
113. Prokofiev, A. A. Some physiological peculiarities of the sunflower as an oil plant. Agrochimica 2 (4):334–349. Ref. Sept. 1958.
114. Rai, G. S., and Hamner, C. L. Some observations on the growth regulating properties of 4–thianaphtheneacetic acid. Mich. Agr. Expt. Sta. Q. B. 41 (2):388–394. Nov. 1958.
115. Rao, S. N., Wittwer, S. H., and Watson, D. P. Some morphological studies of maleic hydrazide induced dormancy in potatoes and onions. Indian J. Hort. 15 (1):1–3. Ref. Mar. 1958.
116. Roberts, R. H., and Struckmeyer, B. E. The nature and activity of naturally occurring growth substances. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):147–148. 1954, pub. 1957.
117. Rufelt, H. Influence of growth substances upon the geotropism of wheat roots. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):125–128. 1954, pub. 1957.
118. Rumburg, C. B. The effect of environmental factors on the herbicidal activity and mode of action of selected arsenic compounds. Diss. Abs. 19 (7):1510. Jan. 1959.

119. Smith, R. J. The differential varietal responses of rice to 2,4–D as influenced by the stage of growth and rate of application. (Abs.) South. Weed Conf. Proc. 10:74–75. 1957.
120. Soog, F., and Niedergang, E. Auxin relations in polarity and morphogenesis. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):123–125. 1954, pub. 1957.
121. Westeringh, S. Van De, and Veldstra, H. Researches on plant growth regulators. XXIV–XXV. Rec. des Trav. Chim. des Pays-Bas 77 (11): 1107–1128. Ref. Nov. 1958.

### D. Morphological and Anatomical Investigations

122. Amato, F. D'. Reactions morphologiques et histologiques induites par le 2,4–D dans l'Asparagus officinalis L. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 7/8):263–265. 1954, pub. 1957.
123. Davis, A. M. Some anatomical effects of sodium 2,2–dichloropropionate on plants. South. Weed Conf. Proc. 10:143–144. 1957.
124. Moja, A., and Spreafico, L. Weed control: remarks on agamic multiplication in the mugwort (Artemisia vulgaris L.). (In Italian.) Ann. della Sper. Agr. (n.s.) 12 (4):1265–1281. 1958.
125. Nečesaný, V. Effect of $\beta$–indoleacetic acid on the formation of reaction wood. Phyton [Buenos Aires] 11 (2):117–127. Ref. Dec. 1958.
126. Prévost, M., Tysset, C., and Vacher, B. Action du 3–parachlorophenyl–1, 1–diméthylurée (monuron ou CMU) sur les mitochondries chez l'Allium cepa; étude en contraste de phase. B. de Micros. Appl. (ser. 2) 8 (4): 101–104. Ref. Aug. 1958.
127. Zanardi, D., and Corte, A. Unusual alteration of grape clusters caused by 2,4–D. (In Italian.) Colt. e Gior. Vinic. Ital. 104 (9):232–233. Sept. 1958.

## III. Weed Control

### A. Cultural

128. Cook, C. W. Sagebrush eradication and broadcast seeding. Utah. Agr. Expt. Sta. B. 404, 23 p. Ref. 1958.
129. Herbel, C., Ares, F., and Bridges, J. Hand-grubbing mesquite [Prosopis juliflora glandulosa] in the semidesert grassland. J. Range Mangt. 11 (6): 267–270. Nov. 1958.
130. Jensen, L. A. Cultural control of wild oats. Nowest. Crop Impr. Assoc. Ext. Conf. [Rpt.] 1957:25.
131. Katsarov, K. Contribution on the question of fighting the chick-weed in the rice fields by means of irrigation. (In Bulgarian.) Plovdiv. Nauch.-Izsled. Inst. po Zelenchukovite Kult. "Maritsa." Nauch. Trudove 1:223–236. Ref. 1957.
132. Mather, J. H., and Greaney, F. J. Wild oat control by cultural methods. Line Elevators Farm Serv. C. 11, rev., 7 p. Oct. 1958.
133. Wolfe, J. S., and Horton, D. E. Investigations on the clearing of weeds from bulb beds by flaming. J. Agr. Engin. Res. 3 (4):324–335. 1958.

### B. Chemical

#### 1. *Weeds in field crops*

134. Bates, J. F. Developments in weed and pest control in sugarcane in British Guiana. Brit. West Indies Sugar Assoc. Proc. Mtg. Sugar Technol. 1957: 100–104.
135. Baudyš, E. Fighting against weeds in seed cultures of clovers. (In Czech.) Pícninárství a Krmivová Zákl. 2 (6):135–137. June 1958.
136. Burgis, D. S. Pre- and post-emergence weed control in sweet corn. South. Weed Conf. Proc. 10:50–53. 1957.
137. Chappell, W. E., and Laprade, J. L. Results of a two year study of weed control in tobacco seed beds. South. Weed Conf. Proc. 10:76–81. 1957.
138. Chappell, W. E. Comparison of granular and spray application of herbicides on peanuts. South. Weed Conf. Proc. 10:87–94. 1957.

139. Ciferri, R. Weeds of the Pavia and Vercelli rice fields before and after control measures. (In Italian.) Riso 7 (11):9–12. Nov. 1958.
140. Cleasby, T. G. The control of weeds by chemicals; three experiments carried out by the Tongaat Sugar Company Ltd. So. African Sugar Technol. Assoc. Proc. 31:119–123. 1957.
141. Coiteux, F. Les mauvaises herbes dans les cultures de mise en conserves, les pommes de terre et la betterave à sucre. Agriculture [Montreal] 15 (6): 171–172, 192. Nov./Dec. 1958.
142. Csávás, I. Ein gefährliches ausländisches. Unkraut in den ungarischen Reiskulturen. (In Hungarian.) Bot. Közlem. 47 (3/4):354–356. 1958.
143. Eckroth, E. G., Holst, E. M., and Cormany, C. E. Chemical control of annual grasses in sugar beets in Montana, Wyoming, and Colorado. Amer. Soc. Sugar Beet Technol. J. 10 (2):156–164. July 1958.
144. Enrile, P. C. Chemical weed control trials at Sto. Tomas demonstration farm. Philippine Sugar Inst. Q. 4:65–66, 91. June 1958.
145. Everett, C. F. Use of herbicides in the control of weeds in potatoes in the Atlantic Provinces. Agr. Pesticide Tech. Soc. Proc. 5:50–53. 1958.
146. Felletti, G. Chemical weed control in grain. (In Italian.) Agr. della Spezia 6 (2):43–45. Feb. 1959.
147. Fitzgerald, J. N. Weed control in lucerne. New Zeal. Weed Control Conf. Proc. 10:86–91. 1957.
147A. Furtick, W. R. Herbicides for better seed. Crops & Soils 11 (6):16. Mar. 1959.
148. Guzman, V. L. Post-emergence grass and weed control in sugar cane. South. Weed Conf. Proc. 10:46–49. 1957.
149. Hernandez Orozco, J. V. Experimentación con herbicidas. B. Azucarero Mex. 116:12–16. Feb. 1959.
150. Horst, K. Ter. Weed control in leguminous crops. (In Dutch.) Surinaamse Landb. 6 (2):65–71. 1958.
151. Kitchin, J. T. Quack grass [Agropyron repens] control in sweet corn. N. H. Prog. Rpt. 4 (2):12–14. June 1958.
152. Klingman, G. C. Corn: comparison of three nitrogen sources for weed control and side-dressing. South. Weed Conf. Proc. 10:54–58. 1957.
153. Klingman, G. C. Corn: preemergence weed control. South. Weed Conf. Proc. 10:59–63. 1957.
154. Klingman, G. C. Tobacco: weed control in field grown tobacco. South. Weed Conf. Proc. 10:82–85. 1957.
155. Leafe, E. L. Spraying of barley with 2,4–diechlorophenoxyacetic acid. Nature [London] 183 (4661):621–622. Feb. 28, 1959.
156. Lifshitz, N. Control of broad-leaved weeds in winter legumes. (In Hebrew.) Hassadeh 39 (3):227–229. Dec. 1958.
157. McLeod, C. Lucerne tolerance. New Zeal. Weed Control Conf. Proc. 10:81–85. 1957.
158. McWhorter, C. G., and Holstun, J. T. Progress report on CIPC and diuron for pre-emergence weed control in cotton. South. Weed Conf. Proc. 10:31–38. 1957.
159. Naidu, B. A., and Singh, D. J. C. Studies on the effects of 2,4–D and MCPA on ragi crop (Eleusine coracana Gaertn.) and weeds. Indian Bot. Soc. J. 37 (3):343–352. Ref. 1958.
160. Nouel, P. Essais sur le semis mecanique en lignes et le desherbages des rizieres. B. d'Inform. des Riziculture de France 58:1–2. Oct./Nov. 1958.
161. Parker, C., and Ashby, D. G. Recent work on control of weeds in maize. (Abs.) World Crops 11 (1):23. Jan. 1959.
162. Pearse, F. S. Low cost weed control in soybeans. Down Earth 14 (4):7–8. Spring 1959.
163. Pfeiffer, R. K., and Burleigh, R. Selective weed control in sorghum (dura). (Abs.) World Crops 11 (1):23. Jan. 1959.
164. Porter, W. K., and others. A critical evaluation of the use of pre-emergence herbicides for weed control in cotton. (Abs.) South. Weed Conf. Proc. 10:29. 1957.
165. Rea, H. E. Perennial vines in fields. South. Weed Conf. Proc. 10:174–177. 1957.

166. Rea, H. E. The control of Johnsongrass in row crops. South. Weed Conf. Proc. 10:154–157. 1957.
167. Reid, T. P. Control weeds for high quality cotton. S. C. Agr. Res. 5 (2):7. Apr./June 1958.
168. Rivera, H. A. Control of weeds in sugar cane with 2,4–D and dalapon in Latin America. (Abs.) Sugar y Azucar 53 (11):70. Nov. 1958.
169. Rochecouste, E. Comparative effectiveness of MCPA and 2,4–D derivatives in pre-emergence control of weeds in sugar-cane in Mauritius. (Abs.) World Crops 11 (1):24. Jan. 1959.
170. Shear, G. M. Current evaluation of chemicals for weed control in corn. South. Weed. Conf. Proc. 10:64–73. 1957.
171. Stamper, E. R. The effect of chemical combinations as herbicides on Johnson grass control in Louisiana sugarcane. South. Weed Conf. Proc. 10:40–45. 1957.
172. Stephens, D. Experiments on the chemical control of weeds in maize in Ghana. Pesticides Abs. & News Sum. Sect. C 4 (4):225–232. Oct. 1958.
173. Stephens, D. Weed control in swamp rice in Ghana. Pesticides Abs. & News Sum. Sect. C. 4 (4):233–237. Oct. 1958.
174. Szczypinski, W., and Kownacki, M. Introductory investigation on herbicides: the control of weeds in oats. (In Polish.) Rocz. Nauk Roln. Ser. A, Roślinna 77 (4):611–613. 1958.
175. Tatura, V. L. To extend the chemical weeding of flax. (In Russian.) Lën i Konoplia 4 (1):31–32. Jan. 1959.
176. Tennessee. University. College of Agriculture and Home Economics. Extension Serv. Chemical weed control guide for field crops. Tenn. Agr. Col. Ext. P. 385, 14 p. Mar. 1958.
177. Thellot, B. Céréales et traitements aux colorants nitrés. B. des Cent. d'Etude Tech. Agr. 46:3–5. Feb. 1958.
178. Ubrizsy, G. Chemische Unkrautbekämpfung in Getreidesaaten. (In Hungarian.) Budapest. Magyar Tudo. Akad. Agrtudo. Osztályának. Közlem. 14 (4):393–414. Ref. 1958.
179. Waddle, B. A., and others. The response of selected cotton varieties to pre-emergence herbicides. (Abs.) South. Weed Conf. Proc. 10:39. 1957.
180. Watson, A. J., and Nation, H. A. Response of peanuts and annual weeds to early post-emergence applications of the alkanolamine salt of DNBP. South Weed Conf. Proc. 10:95–100. 1957.
181. Zanardi, D. Weed control tests on alfalfa. (In Italian.) Colt. e Gior. Vinic. Ital. 104 (10):276–278. Ref. Oct. 1958.

### 2. *Weeds in horticultural crops*

182. Chappell, W. E. The use of granular herbicides in Azaleas. South. Weed Conf. Proc. 10:105–107. 1957.
183. Coupin, A. Encore des dommages causés a la vigne par les herbicides. Vignobles Jard. et Vergers de Tunisie 15:3–9. Dec. 1958.
184. Curtis, O. F. Chemical control of grass & weeds around apple trees. N. Y. State Hort. Soc. Proc. 103:85–89. 1958.
185. Day, B. E., and McCarty, C. D. Monuron for weed control in citrus. Calif. U. Agr. Ext. L. 95, 16 p.-folder. Nov. 1957.
186. Day, B. E. Weed control programs for citrus, avocado orchards. Calif. Citrog. 44 (2):44, 60–61. Dec. 1958.
187. Dermine, M. E. Rôle des herbicides chimiques en culture fruitère Basses-Tiges. Fruit Belge 26 (208):197–200. (Concl.) Dec. 1958.
188. Dion, A. Les mauvaises herbes dans les cultures maraîchères. Agriculture [Montreal] 15 (5):141–142. Sept./Oct. 1958.
189. Foreman, M. S. Weed control in certain horticultural crops. New Zeal. Weed Control Conf. Proc. 10:62–67. 1957.
190. Gal, M. Weed-free soils in vineyards. (In Hebrew.) Hassadeh 39 (2):165. Nov. 1958.
191. Gausman, H. W., and Trevett, M. F. Studies on the retention of radioactive dalapon (Na–2,2–dichloropropionate–2–$C^{14}$). Maine Farm Res. 6 (3):17–22. Oct. 1958.

192. Guyot, H., and Olivier, P. Herbicides par atomisation. 2. Fruits 13 (8): 325–327. Sept. 1958.
193. Guyot, H., and Olivier, P. Les traitements pesticides a débit réduit en culture fruitière tropicale; herbicides par atomisation. 2. Fruits 13 (8): 325–328. Sept. 1958.
194. Guzman, V. L. Pre- and post-emergence weed control in cabbage growing on organic soils. South. Weed Conf. Proc. 10:108–111. 1957.
195. Harranger, J. Les cuscutes dans les cultures florales. Phytoma 10 (101): 20–22. Sept./Oct. 1958.
196. Hill, R. G. Use of chemical weed control in strawberry production. Ohio State Hort. Soc. Proc. 111:131–141. 1958.
197. Ivens, G. W. Control of couch grasses in coffee. (Abs.) World Crops 11 (1):24. Jan. 1959.
198. Julliard, B. Essais de désherbage chimique de la vigne à la Station de Recherches Viticoles de Colmar (I.N.R.A.) Prog. Agr. et Vitic., Sept. 30, 1958: 153–158; Oct. 15, 1958: 179–182.
199. Luckwill, L. C., and Campbell, A. I. The control of bindweed [Convolvulus arvensis, and Calystegia sepium] in black currants. Bristol. U. Agr. & Hort. Res. Sta. Annu. Rpt. 1957:68–71.
200. McCallum, D. W. Weed control in horticultural crops. New Zeal. Weed Control Conf. Proc. 10:59–61. 1957.
201. Noll, C. J. Dinitro band spraying best for weeding limas, snap beans. Sci. Farmer [Pa. Sta.] 5 (4):11. Spring 1958.
202. Oorschot, J. L. P. Van, Staalduin, D., and Zweep, W. Van Der. La destruction du chiendent [Agropyron repens] en culture fruitière, par voie chimique. Fruit Belge 26 (206):165–168. Oct. 1958.
203. Overman, A. J. Effectiveness of various soil fumigants in commercial production of Chrysanthemums. Fla. State Hort. Soc. Proc. 71:394–400. Ref. 1958.
204. Reynolds, J. D. Weed control in peas: a practical guide. Gt. Brit. Min. Agr. Fisheries & Food. Agriculture 65 (1):558–563. Feb. 1959.
205. Ries, S. K., and others. Chemical weed control for vegetables and small fruits. Mich. State U. Ext. Ext. Folder F–241, 10 p. Mar. 1958.
206. Robinson, D. W. The chemical control of grass in fruit plantations. North. Ireland. Min. Agr. Res. & Expt. Rec. 7:72–78. 1957, pub. 1958.
207. Robinson, J. B. D. Chemical weed control in coffee. Coffee & Tea Indus. 81 (11):100–101, 103, 105. Ref. Nov. 1958.
208. Salinger, J. P. Chemical weed control in Gladiolus. New Zeal. J. Agr. 97 (6):535–536. Dec. 15, 1958.
209. Schmidt, H. Uber den Einsatz von Herbiziden im Hackfruchtbau und in Spezialkulturen. Deut. Akad. der Landwirtwiss. Sitzber. 6 (4), 31 p. Ref. 1957.
210. Simanton, W. A. Weed control in citrus planting sites. Citrus Indus. 40 (2):9–10, 18–20. Feb. 1959.
211. Simanton, W. A. Weed control in citrus planting sites. Fla. State Hort. Soc. Proc. 71:114–118. 1958.
212. Stadtherr, R. J., and Widmer, R. E. Chemical weed control in garden Chrysanthemums [C. morifolium]. Weeds 7 (1):82–87. Jan. 1959.
213. Stettmeier, W. Erfahrungen mit Simazin im Gartenbau. Pflanzenschutz 10 (11):123–124. Nov. 1958.
214. Swingle, H. D., and Colditz, P. Pre-emergence weed control in spinach. South. Weed Conf. Proc. 11:90–92. 1958.
215. Thompson, F. B. Weed control in peas. New Zeal. Weed Control Conf. Proc. 10:68–74. 1957.
216. Wallis, J. A. N. Herbicides in Kenya coffee. Pesticides Abs. & News Sum. Sect. C 4 (3):146–172. July 1958.
217. Williamson, J. Las malezas en los jardines de la Provincia de La Pampa. Soc. Argentina de Hort. B. 16 (112):165–168. Oct./Dec. 1958.

### 3. *Weeds in grasslands, including grass-legume pastures, rangeland, turf, lawns, and cemeteries*

218. Alley, H. P., and Bohmont, D. W. Big sagebrush control—what, where, when, why? Wyo. Agr. Expt. Sta. B. 354, 8 p. Feb. 1958.

219. Bockholt, E. B. Selective control of Dallisgrass in Bermudagrass turf. South. Weed Conf. Proc. 10:170–172. 1957.
220. Cook, C. W. Sagebrush eradication and broadcast seeding. Utah. Agr. Expt. Sta. B. 404, 23 p. Ref. 1958.
221. Edmond, D. B. The spraying of establishing pastures. New Zeal. Weed Control Conf. Proc. 10:99–103. 1957.
222. Fisher, C. E. Control of three major brush species on grazing lands in the United States, Cuba and Brazil. South. Weed Conf. Proc. 10:112–117. 1957.
223. Fryer, J. D. Get rid of weeds. Dairy Farmer [Ipswich] 6 (3, sup.):17, 19. Mar. 1959.
224. Glue, D. I. Pasture management and weed control. New Zeal. Weed Control Conf. Proc. 10:29–33. 1957.
225. Grigsby, B. Lawn weed control. Mich. State U. Ext. Ext. Folder F–261, 10 p. June 1958.
226. Ivens, G. W. The effects of arboricides on East African trees and shrubs. I. Acacia species. Trop. Agr. [St. Augustine] 35 (4):257–271. Ref. Oct. 1958.
227. Kramer, M. Selective herbicides for forage legumes. (In Portuguese.) Biológico 24 (7):130–133. July 1958.
228. Leonard, O. A. Control of woody plants on Western ranges. Joint Comt. Grassland Farming. Grassland Proc. 1957:73–86.
229. MacLean, S. M. Effect of time of spraying on pasture production. New Zeal. Weed Control Conf. Proc. 10:34–43. 1957.
230. Shear, G. M. The use of CIPC on mixed plantings of alfalfa and orchard grass. South. Weed Conf. Proc. 10:173. 1957.
231. Thompson, F. B. Weeds in new pastures. Ruakura Farmers' Conf. Week. Proc. 1958:159–163.
232. Youngner, V. B., and Fuchigami, T. The control of crabgrass [Digitaria sanguinalis] in established turfgrasses. South. Calif. Turfgrass Cult. 8 (4): 28–29. Oct. 1958.
233. Ziegenbein, G. Unkrautbekämpfung im Grassamenbau. Pflanzenschutz 10 (10):118–121. Oct. 1958.

4. *Weeds in specialized areas, including ditchbanks, canal ditches, fencerows, rights-of-way, irrigation ditches, and cities*

234. Garmhausen, W. J. Weed control on highways. South. Weed Conf. Proc. 10:6–10. 1957.
235. King, J. R., Simanton, W. A., and Kretchman, D. W. Chemical control of weeds in Florida citrus grove ditches. Fla. State Hort. Soc. Proc. 71:157–166. 1958.
236. Parris, C. G. Railroads battle against weeds. South. Weed Conf. Proc. 11:74–77. 1958.
237. Prescott, L. H., and Francisco, D. C. Field investigations of the use of various herbicides on TVA rights-of-way. South. Weed Conf. Proc. 11:78–82. 1958.
238. Prescott, L. H., and Mann, R. A. Trichlorobenzoic acid small-plot tests on TVA rights-of-way. South. Weed Conf. Proc. 11:83–85. 1958.
239. Price, L. N. Lower-cost roadside maintenance by spraying. Natl. Res. Council. Highway Res. Bd. Comt. Roadside Devlpmt. Rpt. 1958:41–47.
240. Quarles, J. P. Railroad weed control problems. South. Weed Conf. Proc. 10:26–28. 1957.
241. Sterry, J. R. Weed control on railway tracks. Brit. West Indies Sugar Assoc. Proc. Mtg. Sugar Technol. 1957:96–99.
242. Wilson, R. A progress report on the use of herbicides in Essex County. N. J. Mosquito Extermin. Assoc. Proc. 45:165–168. 1958.

5. *Woody plants*

243. Alley, H. P., and Bohmont, D. W. Big sagebrush control—what, where, when, why? Wyo. Agr. Expt. Sta. B. 354, 8 p. Feb. 1958.
244. Beatty, R. H. General aspects of brush control. South. Weed Conf. Proc. 10:18–25. 1957.

245. Darrow, R. A. Aerial spraying with 2-(2,4,5-TP) and 2,4,5-T for control of post and blackjack oaks. South. Weed Conf. Proc. 10:120–123. 1957.
246. Darrow, R. A., and McCully, W. G. Comparison of granular forms of urea herbicides in aerial and hand broadcast applications for the control of post and blackjack oak. South. Weed Conf. Proc. 10:124–128. 1957.
247. Darrow, R. A. Trichlorobenzoic acid and associated herbicides in the control of woody plants in Texas. South. Weed Conf. Proc. 10:132–138. 1957.
248. Manitoba Weeds Commission. Destroy European Buckthorn. Manitoba. Dept. Agr. & Immigr. P. 302, 3 p. May 1958.
249. Massachusetts. University. Agricultural Extension Serv. Chemical control of woody plants. Mass. U. Agr. Ext. P. 323, 6 p.-folder. July 1958.
250. McCully, W. G. Some factors concerning the use of granular herbicides for brush control. South. Weed Conf. Proc. 10:129–131. 1957.
251. Ray, H. C. Aerial chemical reduction of hardwood brush as a range improvement practice in Arkansas. J. Range Mangt. 11 (6):284–290, map. Ref. Nov. 1958.
252. Sluder, E. R. Control of cull trees and weed species in hardwood stands. U. S. Forest Serv. Soeast. Forest Expt. Sta. Sta. Paper 95, 13 p. Ref. Sept. 1958.
253. Walker, L. C. Brush control in the Georgia Piedmont. J. Range Mangt. 12 (1):16–18. Jan. 1959.

### 6. *Aquatic weeds*

254. Kachroo, P., and Sharma, J. C. Further observations on the effects of a few herbicides on the aquatic flora of Bokaro reservoir. Indian J. Malariol. 12 (3):253–257. Sept. 1958.
255. Timmons, F. L., and Fleming, R. Water wasters of the West. Crops & Soils 11 (3):12–13. Dec. 1958.
255A. Van Overbeek, J., Hughes, W. J., and Blondeau, R. Acrolein for the control of water weeds and disease-carrying water snails. Science 129 (3345): 335–336. Feb. 6, 1958.

### 7. *Specific weeds*

256. Beggs, J. P., and Leonard, W. F. Nassella tussock control: preventing reversion. New Zeal. J. Agr. 97 (3):211. Sept. 15, 1958.
257. Blick, C. M. Control of kikuyu grass [Pennisetum clandestinum]. New Zeal. Weed Control Conf. Proc. 10:24–28. 1957.
258. Bylterud, A. Control of couch grass (Agropyron repens P.B.) with trichloroacetic acid. Acta Agr. Scand. 8 (3):265–278. Ref. 1958.
259. Bylterud, A. Tyning av kveke [Eradication of quackgrass]. Norway. Landbrdept. Opplysningstjenesten. Smaskr. 4, 4 p. 1958.
260. Carpenter, W. J. G. New chemical vanquished Veronica in test. Gard. Merchandiser Supply 10 (2):126, 128. Feb. 1959.
261. Chaffin, W. Bindweed control in Oklahoma. Okla. State U. Agr. Ext. C. E–668, 8 p. July 1958.
262. Dawes, S. N. Brassica weed control. New Zeal. Weed Control Conf. Proc. 10:75–80. 1957.
263. Derscheid, L. A. Russian knapweed [Centaurea repens]. S. Dak. Farm & Home Res. 9 (3):16–23. May 1958.
264. Dunham, R. S. Control of wild oats with chemicals. Nowest. Crop Impr. Assoc. Ext. Conf. [Rpt.] 1957:24.
265. Friesen, H. A., and Forsberg, D. E. Neburon as a selective herbicide for tartary buckwheat [Fagopyrum tataricum] and wild buckwheat [Polygonum convolvulus]. Weeds 7 (1):47–54. Jan. 1959.
266. Fryer, J. D. Control of bracken with dalapon; recent developments in Great Britain. Down Earth 14 (4):11–14. Spring 1959.
267. Fuchigami, T., and Younger, V. B. Kikuyugrass, Pennisetum clandestinum, and its control. South. Calif. Turfgrass Cult. 8 (4):31–32. Oct. 1958.
268. Geshele, E., and Zhukov, I. Chemical control of European bindweed [Convolvulus arvensis]. (In Russian.) Sel'sk. Khoz. Sibiri. 1958 (6):35–37.

269. Goodrum, P. D., and Gray, C. E. Experimental control of giant cutgrass [Zizaniopsis miliacea] in eastern Texas. Down Earth 14 (3):10–12. Winter 1958.
270. Grandy, D. C. Sprayed sagebrush "growing itself to death" in Utah. Natl. Wool Grower 49 (2):41. Feb. 1959.
271. Granström, B. Quackgrass control. (In Swedish.) Beten-Vallar-Mossar 10 (9):120–122. Oct. 1958.
272. Gualba, C. La orobanquia de los habares. Cult. Mod. 41 (12):462. Dec. 1958.
273. Hauser, E. W., and Thompson, J. T. Responses of Johnson grass to preplanting treatments with disking and herbicides. (Abs.) South. Weed Conf. Proc. 10:153. 1957.
274. Hauser, E. W. Nutgrass [Cyperus rotundus]—a formidable foe. South. Weed Conf. Proc. 10:166–169. 1957.
275. Jooste, J. Van Der W. Control wild morning glory [Convolvulus arvensis] with hormone-type weedkiller. Farming So. Africa 34 (7):39–40. Oct. 1958.
276. Klingman, G. C., and Rud, O. E. Striga: a threat to corn and other summer grass crops. South. Weed Conf. Proc. 10:178–186. 1957. Bibliography, p. 181–186.
277. Kolmakov, P. Biological peculiarities of wild oat [Avena fatua] and its control in Siberia. (In Russian.) Sel'sk. Khoz. Sibiri 1958 (10):32–41. Oct.
278. Leasure, J. K. Some common weeds and their control. Tenn. Agr. Col. Ext. P. 370, 91 p. June 1957.
279. Linck, A. J., and Kommedahl, T. Canada thistle [Cirsium arvense]—spotlight on a troublesome weed. Minn. Farm & Home Sci. 15 (3):21–22. May 1958.
280. O'Neil, J. M. Noogoora burr, Californian burr, buffalo burr—these weeds must go. So. Austral. Dept. Agr. J. 62 (1):7–11. Aug. 1958.
281. Parsons, W. T. Furze an "old English" weed. J. Agr. [Melbourne] 56 (12): 799–803. Dec. 1958.
282. Ruskin, J. H. How Detroit KO'd ragweed. Amer. City 74 (2):100–101. Feb. 1959.
283. Sparrow, D. M. L. Nutgrass (Cyperus rotundus) and its control; a review. Pesticides Abs. & News Sum. Sect. C 4 (3):135–145. Ref. July 1958.
284. Sperry, O. E. The chemical control of Texas buckeye (Aesculus arguta Buckl.). South. Weed Conf. Proc. 10:118–119. 1957.
285. Stamper, E. R. The problem of Johnson grass. South. Weed Conf. Proc. 10:149–152. 1957.
286. Vallance, L. G. Guinea grass and para grass control. Queensland. Bur. Sugar Expt. Sta. Cane Growers' Q. B. 22 (2):66–68. Oct. 1, 1958.
287. Vance, J. E. Controlling bitterweed [Hymenoxys odorata]. Tex. Agr. Prog. 4 (4):17, 19. July/Aug. 1958.
288. Wiese, A. F., and Rea, H. E. Blueweed control. Tex. Agr. Expt. Sta. Prog. Rpt. 2052, 3 p. Aug. 28, 1958.
289. Wilkerson, J. A., and others. Chemical and cultural studies on the control of nutgrass [Cyperus rotundus] in cotton. South. Weed Conf. Proc. 10: 158–165. 1957.
290. Yeates, J. S. Control of barley grass [Hordeum murinum] by spraying. Massey Agr. Col. Sheepfarming Annu. 1958:173–175.

### C. Biological

291. Moja, A. Means of weed control; lucerne in relation to mugwort (Artemisia vulgaris L.). (In Italian.) Ann. della Sper. Agr. (n.s.) 12 (4):1115–1126. 1958.
292. Swingle, H. S. Control of pond weeds by the use of herbivorous fishes. South. Weed Conf. Proc. 10:11–17. Ref. 1957.

## IV. Chemical and Biochemical Investigations

293. Beck, E., and Walker, L. C. Extraction of $C^{14}$-tagged 2,4–D and 2,4,5–T from woody plants. South. Weed Conf. Proc. 11:68–71. 1958.

294. Clendenning, K. A. Recent investigations of photosynthesis and the Hill reaction. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):21–35. Ref. 1954, pub. 1957.
295. Dugger, W. M., Humphreys, T. E., and Calhoun, B. Influence of N–(trichloromethylthio)–4–cyclohexene–1,2–dicorboximide (captan) of higher plants. II. Effect on specific enzyme systems. Amer. J. Bot. 46(3):151–156. Ref. Mar. 1959.
296. Fawcett, C. H., and others. Plant growth-regulating activity in homologous series of $\omega$–phenoxyalkanecarboxylic acids and the influence of ring substitution on their breakdown by $\beta$–oxidation within plant tissues. Roy. Soc. London. Proc. Ser. B, Biol. Sci. 150(938):95–119. Ref. Jan. 27, 1959.
297. Krewson, C. F., and others. Plant growth regulators: synthesis and preliminary evaluations of amide, lactic acid, and terpenoid derivatives of substituted phenoxycarboxylic acids. J. Agr. & Food Chem. 7(2):118–122. Ref. Feb. 1959.
298. Patwardhan, N. B., and Ganpule, T. V. Preharvest spraying of synthetic hormone 2,4–D sodium salt to step up sugar-recovery. Deccan Sugar Technol. Assoc. (India). Annu. Conv. 15(1):138–139. 1958.
299. Pybus, M. B., Wain, R. L., and Wightman, F. New plant growth-substances with selective herbicidal activity. Nature [London] 182(4642):1094–1095. Oct. 18, 1958.
300. Sciuchetti, L. A., and Youngken, H. W. The effects of atropine and 2,4–dichlorophenoxyacetic acid on leaf alkaloid accumulation in certain members of the Solanaceae. Amer. Pharm. Assoc. J. Sci. Ed. 47(11): 803–807. Ref. Nov. 1958.
301. Stowe, B. B., Ray, P. M., and Thimann, K. V. The enzymatic oxidation of indole acetic acid. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Sér. 8(sect. 11/12):135–140. 1954, pub. 1957.
302. Wain, R. L. Relation of chemical structure to activity for 2,4–D-type herbicide and plant growth regulator. Advn. Pest Control Res. 2:263–305. Ref. 1958.
303. Yost, J. F., and Williams, E. F. Some residue and metabolism findings in the development of 3–amino–1,2,4–triazole. Agr. Pesticide Tech. Soc. Proc. 5:1–5. 1958.

## V. Special Plants and Their Control

### A. Poisonous Plants and Their Control

304. Coup, M. R. Common plants poisonous to stock. New Zeal. J. Agr. 98(1):61, 63, 65, 67, 69. Jan. 15, 1959.
305. Coup, M. R. Common plants poisonous to stock. Ruakura Farmers' Conf. Week. Proc. 1958:141–153.
306. Gonzalez, M. H., and Martinez Martinez, F. Las plantas tóxicas al ganado en los pastizales de Chihuahua. Mex. Ofic. de Estud. Espec. Fol. de Divulg. 28, 27 p. Ref. Sept. 1958.
307. Kamel, S. H. The toxicological investigation of the Egyptian plant, Polygonum equisetiforme. Cairo U. Facul. Vet. Med. Vet. Med. J. 4(4):201–208. 1957, pub. 1958.
308. Martinez Martinez, F. Plantas venenosas en los pastizales de Chihuahua. Agr. Téc. en Méx. 6:22–23, 50–51. Summer 1958.
309. McLean, A., and Nicholson, H. H. Stock poisoning plants of the British Columbia ranges. Canada. Dept. Agr. P. 1037, 31 p. Ref. Aug. 1958.
310. Millard, A. H., and Orr, W. Observations on the toxicity of Sarcolobus globosus, Wall. Malayan Vet. Med. Assoc. J. 2(1):24–30. July 1958.
311. Morton, J. F. Ornamental plants with poisonous properties. Fla. State Hort. Soc. Proc. 71:372–380. 1958.
312. Rautenberg, L. E., J. C. A. Mayer's Einheimische Giftgewächse (1798–1801). Soc. Bibliog. Nat. Hist. J. 3(6):325–327. Dec. 1958.
313. Sperry, O. E. Poisonous range plants. XIX. Pokeweed [Phytolacca americana], wild plums and wild cherries [Prunus spp.]. Sheep & Goat Raiser 39(2):26–27. Nov. 1958.

B. Uses of Weeds

C. Pathological and Entomological Relationships

314. Potter, H. S., and Turner, M. E. Control stem rust by barberry eradication. Mich. State U. Ext. Ext. Folder F–158, 6 p. June 1958.

VI. Nature and Properties of Chemicals Used as Herbicides

315. Alderman, D. C. Chemical thinning. Amer. Fruit Growers 79 (3):22–23. Mar. 1959.
316. Batjer, L. P. Thinning apples with chemical sprays. Va. Fruit 47 (2):26, 28, 30, 32. Feb. 1959.
317. Bell, J. E. Work with dalapon. New Zeal. Weed Control Conf. Proc. 10:104–107. 1957.
318. Burmistrov, S. I., and Vlasova, O. Kh. Synthesis of herbicides. 1. (In Russian.) Ukrain. Khim. Zhur. 24 (5):629–631. 1958.
319. Carter, E. P. Report on volatility of ester forms of hormone type herbicides. Assoc. Off. Agr. Chem. J. 42 (1):100. Feb. 1959.
320. Crafts, A. S., Currier, H. B., and Drever, H. R. Some studies on the herbicidal properties of maleic hydrazide. Hilgardia 27 (22):723–757. Ref. Oct. 1958.
321. Craig, H. A., Friesen, G., and Hendrickson, M. F. Chemicals for weed control. Manitoba. Dept. Agr. Immigr. P. 300, 16 p. Apr. 1958.
322. Drake, D. C. Substituted ureas for weed control in crops. South. Weed Conf. Proc. 10:101–104. 1957.
323. Eckstein, Z., and Sobotka, W. On the preparation of weed-killing agents. XI. (In Polish.) Przem. Chem. 37 (8):537–539. Ref. Aug. 1958.
324. Eckstein, Z. Some problems of obtaining weed killers. IX. The action of active bromine on phenoxyacetic acids. (In Polish.) Rocz. Chem. 32 (6): 1357–1363. Ref. 1958.
325. Haddock, L. A., Hill, R., and Jones, A. G. Seven methods of determining the active constituent of MCPA weedkillers. Mfg. Chem. 30 (2):57–60. Ref. Feb. 1959.
326. Hammond, H. Report on herbicides. Assoc. Off. Agr. Chem. J. 42 (1): 107–108. Feb. 1959.
327. Hegelson, E. A. La lucha contra las malas hierbas; el 2,4–D y su preparación. Tierra [México] 14 (1):34, 76. Jan. 1959.
328. Hegelson, E. La lucha contra las malas hierbas. Tierra [México] 13 (11): 978, 1028–1029. (Cont.) Nov. 1958.
329. Khan, M.-Ud-D., and Hameed, A. Studies on the toxicity of weedicides on the subsequent crops. (Abs.) Pakistan Sci. Conf. Proc. 9 (3):20–21. 1957.
330. Kovalev, V., and Tishchenko, D. Herbicides from phenols of resins derived from wood thermolysis. (In Russian.) Zhur. Prikl. Khim. 31 (11): 1708–1715. Ref. Nov. 1958.
331. Lillie, D. T. Effects of carriers and soil incorporation on the efficiency of pre-emergence herbicidal applications. Diss. Abs. 19 (6):1153–1154. Dec. 1958.
332. Linnasalmi, A. Phytotoxicity of wood preservatives and possibilities of using them in greenhouses and benches. Finland. Maatalouden Koet. Keskusvaliokunta. Valtion Maatalouskoet. Julkaisu. 166, 40 p. Ref. 1958.
333. Meeklah, F. A. Experimental work with phenoxy-butyrics. New Zeal. Weed Control Conf. Proc. 10:92–98. 1957.
334. Morris, M. Notes on the possible methods of application of comirin in the control of plant diseases. Cong. Internatl. de Bot. Rap. et Commun. Deuxième Ser. 8(sect. 21/27:70–73. 1954, pub. 1956.
335. Neururer, H. Sind Kombinationen von Wuchsstoff- und Kontaktmitteln zur Unkrautbekämpfung vorteilhaft? Pflanzenarzt 11 (11):117–118. Nov. 1, 1958.
336. Poignant, P. Perfectionnements apportés à l'emploi des colorants. B. des Cent. d'Etudes Tech. Agr. 46:5. Feb. 1958.
337. Richards, R. F. Simazin and related triazines—a progress report. South. Weed Conf. Proc. 11:86–89. 1958.

338. Shaukat, G. A., and Karimullah. Substituted acetic acids (2,4–dichlorophenoxy acetic acid. (Abs.) Pakistan Sci. Conf. Proc. 9 (3):80. 1957.
339. Smirnov, B. M., and Orishchenko, IA. P. The prospective herbicide—sodium pentachlorophenate. (In Russian.) Sel'sk. Khoz. Povolzh'ia 4 (10):51–52. Oct. 1958.
340. Sobotka, W., Eckstein, Z., and Urbanski, T. Some problems of obtaining weed killers. VII. Esters of aryloxyacetic acids and aliphatic nitroalcohols. (In Polish.) Rocz. Chem. 32 (4):963–970. 1958.
341. Soyez, J. L. Herbicides à base de dérivés substitués de l'urée. Chim. & Indus. 81 (2):220–226. Feb. 1959.
342. Stubbs, J. A new herbicide. Outlook Agr. 2 (2):64–68. Winter 1958.
343. Thompson, A. H. Spray thinning of peaches. Amer. Fruit Grower 79 (3): 36, 38, 40. Mar. 1959.
344. Woodford, E. K. Chemical weedkillers—their possibilities and some problems. Farmers' Club J. 1:1–13. 1959.
345. Zick, W. H. Borate soil sterilants for noncrop areas. South. Weed Conf. Proc. 10:190–192. 1957.

### VII. Effect of Herbicides on Soils, Livestock, and Humans

### VIII. Equipment, Methods of Application, and Herbicidal Calculations

346. Borodina, T. R., and Pokroskiĭ, V. E. Effectiveness of small portions of herbicide solutions in weed control by aircraft. (In Russian.) Vest. Sel'skokhoz. Nauki 3 (11):46–50. Nov. 1958.
347. Choyce, M. A. A note on the use of tractor-mounted sprayers on cotton in northern Nigeria. Empire Cotton Growing Rev. 36 (1):12–13. Jan. 1959.
348. Cobbald, T. E. Spray application problems. XLIV–XLV. A compressed air nozzle for small-volume spraying. Bristol. U. Agr. & Hort. Res. Sta. Annu. Rpt. 1957:123–127.
349. Courshee, R. J., and Valentine, R. W. Use of plaster of paris for recording spray drops. J. Agr. Engin. Res. 4 (1):62–65. 1959.
350. Gowing, D. P. A method of comparing herbicides and assessing herbicide mixtures at the screening level. Weeds 7 (1):66–76. Ref. Jan. 1959.
351. Leasure, J. K. A logarithmic-concentration sprayer for small plot use. Weeds 7 (1):91–97. Jan. 1959.
352. Leasure, J. K., and Falkenstein, W. J. A logarithmic concentration sprayer for small plot use. Down Earth 14 (3):2–5. Winter 1958.

### IX. Legal Aspects

353. Epps, E. A. Regulating the use of 2,4–D in the Southern States. Weeds 7 (1):108–110. Jan. 1959.

W. F. HUMPHREY PRESS INC.
GENEVA, N. Y.

# Suggestions for Contributors to WEEDS

Manuscripts dealing with all aspects of weed control, regulatory, educational and research, are accepted for publication in WEEDS. Manuscripts should have more than purely local interest. The material described should be more conclusive than progress reports. Articles must be original material previously unpublished elsewhere. Prior publication in brief abstract form is permitted. After review, each manuscript will be accepted for publication upon recommendation of the Editorial Board. The author has the opportunity to make revisions after the review is completed and before publication. Refer to a recent issue of WEEDS to determine details of style to be used.

*Manuscripts.* Two copies, one on bond paper, should be furnished for each manuscript. The entire text, including the title, footnotes and literature cited, should be doubie spaced. An additional copy of the manuscript should be retained by the author to ensure against loss.

Use as short a title as practical. Following the title give the authors name(s). It is desirable to divide the manuscript into sections with headings such as Methods and Materials, Results, Discussion, Summary, and Literature Cited. "Results" and "Discussion" may often be profitably combined in a single section, and no rigid requirement of the above divisions is implied. Avoid underscoring headings, words or phrases unless you wish them to be printed in italics. Do not use solid capitals for titles.

Measurements such as time, weight and degrees should be in arabic numerals regardless of the number of digits in the number. Where the figure is not one of measurement, figures below 10 should be spelled out except when one figure in a series has two digits in which case all should be in arabic.

The full chemical name or description of all chemicals mentioned should be given the first time used. Nomenclature, abbreviations and definitions should follow those presented in the Terminology Committee Report, WSA, published in WEEDS 6:71–76, Jan., 1958.

*Footnotes.* Use footnotes sparingly for items that cannot be included conveniently in the text. The place where the study was done and the address of the author(s) should be given as footnotes. Number footnotes to the text consecutively throughout the manuscript with superscript arabic numerals. Designate footnotes to the tables with superscript lower case letters.

*Figures.* Experimental data may be presented in graphic or tabular form. However, figures should not be used if they merely illustrate material presented in the text or in tables. Prepare illustrations with approximately the same proportions as a printed page, $4^1/_6$ x 7 inches, or some fraction of a page. Photographs should be clear glossy prints and should be trimmed of unessential portions. Do not use clips on photographs in any way.

Graphs and drawings should be inked with heavy black lines to ensure clarity after reduction in size. Hand lettering should be large and made with a lettering guide. Typing is not acceptable. Place the author's name and figure number on the back of each one submitted. Type the legends for all figures on one sheet separate from the figures, and double spaced. Figures should be numbered consecutively in arabic numerals.

*Tables.* Type each table on a separate sheet. Tables should be numbered consecutively in arabic numerals in order of reference in the text. In tables, the caption, column headings and side headings should be in lower case with only the first word and proper nouns capitalized.

*Citations.* Citations are numbered alphabetically by senior author and the number of the reference is used in the text. Citations should include names of all authors, complete title, volume number, inclusive pages, publication and year. Theses and letters, or any other communication not readily available in libraries, should appear as footnotes.